Vortek Industries Ltd
Vancouver, BC

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SINTERING OF CONTROLLED THICKNESS CERAMIC COATINGS ON METAL USING HIGH INTENSITY LIGHT

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FINAL REPORT

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1. INTRODUCTION

The work carried out in Phase I of the project demonstrated the feasibility of using high intensity Vortek lamps to produce sintered inorganic coatings on steel substrates. Encouraging results were obtained producing porcelain enamel glass coatings and a self-fluxing type tungsten carbide cermet coating applied by spraying and lamp sintering.

In the laboratory experiments undertaken in this program, the stationary Vortek lamp was pointed downwards and the sample moved at a constant rate through the 'line focus' of the lamp. In the future, a full scale Vortek lamp system could be moved across the surface of a large, grit-blasted substrate to sinter a 4" wide 'stripe' across the substrate. The coating could be sprayed immediately ahead of the lamp. At 0.25"/sec lamp movement rate, this translates into 1 sq. ft. coated in 3 minutes or 20 sq.ft./hour. Potentially this may be increased by using a larger line width. The potential for field deposition of extremely corrosion resistant (glass) or abrasion resistant (cermet) coatings was the basic driving force behind the development work undertaken in this program.

A major obstacle to the ultimate application of these Phase I coatings was temporary and permanent warping of the substrate during sintering. Investigations into the causes of the warping and investigation of possible solutions was a main focus of this Phase II program using both cermet and glass coating materials.

It should be noted that all sample designations referred to in this report are prefixed by 94-J23-B6882- or 95-J23-B6882- as part of the ORTECH sample numbering system (for samples prepared in 1994 and 1995 respectively). These prefixes have been dropped only in this report.

2. OBJECTIVES

The objective of this Phase II program were:

1. Reduce substrate warping due to non-uniform irradiance and variations in surface absorption.

2. Investigate the effect of sample thickness on warping and sintering.

3. Determine the feasibility of preparing cermet coatings with limited warping using substrate surface fusion.

3. MILESTONE PROGRESS STAGES

This project was organized into three milestones as described below.

Milestone #1 - Warping causes identified.
Cermet coatings formulated.

Milestone #2 - Minimize warping on glass samples.
Establish feasibility of cermets.

Milestone #3 - Minimize warping on cermets.
Characterization of coatings.
Final report.

4. COATING FORMULATION

The two most promising coating materials for steel substrates identified in Phase I of the program were porcelain enamel type glass and self fluxing type cermet coatings. These materials were used in Phase II for process development, improvement of binders and improved coating parameters as they related to Vortek lamp sintering.

The porcelain enamel-type glass coating used in Phase I and Phase II was Ferro XG684 base coat porcelain enamel manufactured by Ferro Corp., Cleveland, OH. This glass is formulated to adhere to steel substrates and contains a low level of cobalt to enhance bonding. The cobalt results in a blue coloured glass and the thermal expansion coefficient has been controlled to be slightly lower than that of steel. The slightly lower expansion coefficient of the glass results in a low level of compressive stress in the coating upon cooling from fusion temperature. The glass is stress-free at temperatures above the glass annealing point due to viscous flow. The small compressive stress in the glass results in improved chipping and durability of the coating. The corrosion resistance of porcelain enamels is usually excellent (except for very caustic or fluoride-containing acids). Porcelain enamels are used extensively for stoves, ranges and cookware as well as an interior coating for hot water heaters.

The XG684 glass is supplied as frit, which is roller quenched flakes of glass. The glass frit was ground in a pulverizer with alumina plates. The pulverized powder was screened to -100 mesh for ball milling. All coating formulations containing glass in this program were ball milled under identical conditions (except as noted in this report) in a slurry containing the desired binder. Organic binders were milled in acetone or de-ionized water and silicate binders were milled in de-ionized water. Cermets consist of hard ceramic particles dispersed in a metallic matrix. The hard ceramic particles are usually tungsten carbide and occasionally chromium carbide or other borides. The metallic matrix is usually a cobalt rich (or nickel rich) alloy with tungsten carbide (ranging from 6 wt% to >19 wt% metal) or a nickel-chrome alloy with chromium carbide or chromium boride. Dozens of formulations have been optimised and are marketed for a variety of applications using different types of application equipment.

Cermets exhibit both high toughness (because of the metal matrix) and high hardness (because of the carbide particles). Corrosion resistance is limited by the corrosion resistance of the metal matrix or residual coating open porosity. Low levels of closed porosity do not usually affect corrosion resistance. Grinding is required for surface finishing.

The self fluxing cermet which showed potential in Phase I was 34F cermet manufactured by Metco (a division of Perkin Elmer). Metco 34F powder is a blended 50/50 mixture of nickel chromium metal alloy particles and tungsten

carbide/cobalt cermet particles (88% tungsten carbide/12% cobalt cermet blended with NiCr alloy powder). The metal particles in this powder can be metallurgically bonded to a steel substrate when melted in a separate heat treatment resulting in exceptional coating bond strength. Fused coatings of Metco 34F are considerably less hard (Rc54-Rc58) than pure tungsten carbide (Rc75) because of the higher metal content. The very high density of tungsten carbide and the large particle size of atomised cermet (-53μm +15μm diameter for 34F) present serious difficulties for the formation of a stable suspension needed for spray coating techniques.

The coating process development efforts in the Phase II program were undertaken in sets of samples with one coating formulation per set although other factors, such as substrate thickness or substrate preparation were varied as required within one set. The sets of samples prepared in this program were:

Set 87 Dual coating (34F / 9.1% Elvanol on XG684 glass / 16.6% CAB)
91 XG684 glass / 16.6 wt% CAB
94 XG684 glass / 16.6 wt% CAB
96 34F Cermet / 16.6 wt% Elvanol
98 XG684 glass / 10 wt% CAB
103 XG684 glass / 10 wt% CAB
108 'Medium Grind' XG684 glass / 10 wt% CAB
109 'Fine Grind' XG684 glass / 10 wt% CAB
110 XG684 glass / 5 wt% GD sodium silicate binder
111 XG684 glass / 10 wt% GD sodium silicate binder
112 XG684 glass / 15 wt% GD sodium silicate binder / 10 wt% silica
113 XG684 glass / 20 wt% GD sodium silicate binder / 15 wt% silica
114 XG684 glass / 10 wt% CAB
115 34F Cermet / 5 wt% Elvanol

The first step in the processing sequence is the preparation of the substrate. Rolled steel was used as the substrate in this program. All surfaces to be coated were grit-blasted to remove oxides, scale or other debris. Slurries of coating material were spray painted onto grit-blasted steel surfaces except for those grit-blasted surfaces coated with a nickel coating (nickel flash or nickel coated) as per section 8.

All coating slurries were formulated so as to be spray painted onto the grit-blasted substrate. Upon drying, the coating was sintered onto the substrate using the Vortek 300 kW lamp at Vortek Industries in Vancouver, B.C. The Vortek lamp is used to sinter a 'stripe' approximately 4" wide at a distance of 1-2 cm below the lamp reflector focus.

4.1. CAB Binder

CAB-381.20 and CAB-381.01 are solid grades of cellulose acetate butyrate. Both powders were dissolved in acetone to form clear solutions. Since the molecular weight of the 381.20 is higher than that of 381.01, the corresponding non-volatile contents of the two solutions were 9.4% for CAB 381.20 and 29.9% for CAB-381.01. XG684 glass frit was dispersed into the CAB solutions using a high speed disperser. It was found that approximately 10% of the total solvent must be an ester (PM acetate) to give acceptable film formation. Replacement of the ester with an aromatic solvent gives rise to mudcracking in the dry film.

It was also observed that dry films using a CAB binder cannot be recoated with CAB-based coatings since the solvents in the second coat dissolve the basecoat. Therefore, multiple coats are best achieved using a polyvinyl alcohol-based first coat and a CAB-based topcoat.

Detailed formulations can be found in Appendix A.

4.2. Elvanol Binder

Elvanol 51-05 and Elvanol 51-22 are solid grades of polyvinyl alcohol. Both can be readily dispersed in water to form solutions. Since the molecular weight of 51-22 is higher than that of 51-05, the corresponding solution solids contents are lower (22.9% for the 51-05 and 15.0 for the 51-22).

Metco 34F was dispersed into Elvanol solution using a high speed disperser. Disperbyk 130 was added at a level of 1 gram per 1000 grams of total solution to assist in the dispersion process. The resulting solution was reduced to spray viscosity (18"-24" Ford 4 cup) with water and n-butanol.

Detailed formulations can be found in Appendix A.

4.3. Inorganic Binder With Glass Powder

The purpose of this trial series (sample sets 110, 111, 112 and 113) was to assess whether the organic binder used in coating formulations could be replaced with a sodium silicate binder. The use of silicate binders would eliminate the smoke and carbon formation associated with the burnout of the organic binders. The residual sodium silicate tends to dissolve in the XG684 glass upon sintering. The extra sodium silicate slightly increases the coefficient of thermal expansion of the XG684 glass and makes the glass coating less durable.

A series of glass powders was milled in deionized water with 5, 10, 15 and 20 wt% additions of PQ Corp. GD grade sodium silicate. The high sodium silicate additions required additional silica to reduce the total soda content of the glass close to the original level in XG684 glass. The formulations prepared were:

Set 110 5 wt% PQ GD sodium silicate
95 wt% XG684

Set 111 10 wt% PQ GD sodium silicate
90 wt% XG684

Set 112 15 wt% PQ GD sodium silicate
10 wt% Amorphous Silica (BDH)
75 wt% XG684

Set 113 20 wt% PQ GD sodium silicate
15 wt% Amorphous Silica (BDH)
65 wt% XG684

Prior to fusion, the sodium silicate acts as a binder to hold the glass powder onto the steel substrate. Sodium silicate will melt at a much lower temperature than XG684 glass and the sodium silicate will fuse first upon heating. Once the sodium silicate is molten, it will rapidly react with the XG684 glass to form a homogeneous glass. The addition of sodium silicate will decrease the overall melting temperature of the final glass below that of XG684 because of the higher

alkali content of the final glass. Excessive additions of alkali will decrease the durability of the fused coating. For this reason, additional silica was added to the batches with very high sodium silicate levels. GD grade sodium silicate contains 27% soda and 54% silica with the remainder being water. XG684 contains 54% silica as well but also contains other proprietary network modifiers and alkaline earths in addition to alkali (Na and K). The total alkali (Na and K) content of XG684 is not known. It is known that silica additions will increase the melting point and increase chemical durability.

The results of lamp sintering are included in Appendix B. An increase in coating fusion was observed with increased sodium silicate additions at identical lamp powers as shown in Figures 4.3.1 and 4.3.2. The addition of silica to the very high sodium silicate addition levels (15 wt% and 20 wt%) appeared to decrease the fluidity although samples were not processed at 675 A to provide a direct comparison to the 5 and 10 wt% samples. All samples processed at 725 A were over-sintered.

Of particular note in this sintering trial was the drastic reduction in smoke formation and the smoothness of the sintered glass coating. At higher power levels the coating appeared mottled as shown in Figure 4.3.3. Thicker coatings formed isolated beads of glass which crazed off upon cooling as shown in Figure 4.3.4.

4.4. Glass Powder Particle Size

The purpose of this trial was to assess whether the particle size of the glass powder would affect the lamp sintering process on steel substrates. (It should be noted that the particle size of the 34F cermet is much larger than that of the glass powder but particle size reduction of the cermet powder was not feasible within this program.) XG684 glass powder was ball-milled in acetone and organic binder for periods of time in excess of the milling time used for 'normal' slurries. Two milling times were selected to yield batches with particle sizes significantly smaller and mid-way between 'fine' and 'standard'.

The particle size of 'standard' milled XG684 glass powder as a function of ball milling time under standard milling conditions was measured using a Malvern Mastersizer. The effect of ball milling time is presented in Figure 4.4.1 and particle size analysis results are included in Appendix C. These data were used to select

two milling times (12 hours and 36 hours) to prepare glass powders with a 'medium' and 'fine' particle size.

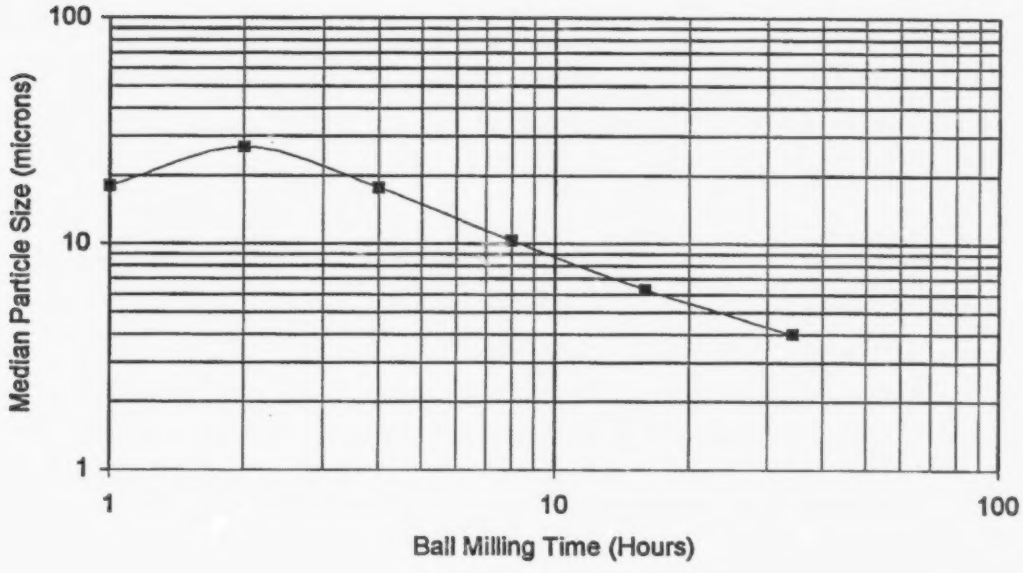

Figure 4.4.1 - Ball Milling of XG684 Glass

The 'mid' glass powder was determined to have a mean (volume) particle size of 10.5 microns and a median particle size of 7.6 microns. The 'fine' glass powder was nominally set to mill for 36 hours but a failure of the mill drive assembly reduced this period. It is known that this batch milled for 24 to 36 hours. The mean (volume) particle size for the 'fine' batch was 5.1 microns and a median of 3.5 microns. The 'medium' and 'fine' ground materials were coated onto 4" x 8" x 0.375" or 0.5" grit- blasted steel substrates as sets 108 and 109.

No significant effects due to the particle size of the starting glass powder in the pre-sintered coating were observed. Sample-to-sample variation was greater than the set-to-set variation between 'standard', 'medium' and 'fine' ground glass powder as shown in Figures 4.4.2 and 4.4.3. It should be noted that both of these samples were coated onto 0.375" thick steel plates rather than the 0.25" plates normally used. The effect of particle size may have been masked by the non-optimum processing conditions and the >5 mil pre-sintered coating thickness. Sintering results are included in Appendix B.

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5. DUAL COATING (CERMET ON GLASS ON STEEL) SERIES

A set of lamp sintering trials (sample set 87) was undertaken with a single sinter, two layer coating of cermet (Metco 34F self-fluxed tungsten carbide cermet) on glass (Ferro XG684 porcelain enamel) in an attempt to combine the abrasion resistance of the cermet with the corrosion resistance of the glass. The purpose of this trial was to assess whether the glass coating could be used to bond the cermet particles onto the steel substrate. The slurry coating data are included in Appendix A and the sintering results are presented in Appendix B.

The glass fused to the substrate but the cermet formed beads on the surface of the glass as shown in Figure 5.1 and at higher magnification, in Figure 5.2. This sintering series was not successful.

The steel substrates used in this series were 0.063" thick x 4" x 6". The substrates were grit-blasted on one side and all samples, except one, were moved through the Vortek lamp across their length at 1.0 cm below the focus of the lamp's reflector. Sample P87-7 was processed along its length. An air sweep across the lamp window was used to sweep away reaction gases and soot in all runs except for sample P87-1.

In most cases, the cermet was fused into small beads prior to fusion of the underlying glass. Optical and SEM examination of cross-sections of selected samples indicates metallurgical bonding of the self-fluxing cermet beads to the steel substrate. This is shown in Figure 5.3 which is an SEM with atomic number contrast enhancement. The carbide particles appear as light areas and the steel substrate is noted as area 5. Upon examination, it appears that a molten metallic phase displaces the glass and then bonds metallurgically to the substrate. A bond line can be seen as area 4 on Figure 5.3 and is a high iron phase containing some nickel and chromium.

Figure 5.4 is an optical micrograph of the cermet coating in cross section after etching to reveal microstructural features. Of special note is a continuous layer of pearlite which has formed on the outermost surface of the steel substrate. Pearlite

is a lamellae microstructure of ferrite (0.02 wt% C) and cementite (6.67 wt% C) with an overall carbon content of <0.8 wt%.

Beads of cermet contain a dispersed tungsten carbide phase with indentation hardness values ranging from 701 VHN to 975 VHN (200 g). An increase in the carbon content of the steel immediately under the bond zone is indicated by the presence of a pearlitic phase. This is shown in Figure 5.4 as the pearlitic phase appears as a dark region under the cermet bead fused. An area of porous glass can be seen as a dark region between the cermet beads in Figure 5.4.

Small areas of some sintered samples appeared metallic after sintering. A cross-section sample was cut from sample P87-5 from an area with the metallic appearance and an optical micrograph of a cross section is shown in Figure 5.5. An even metallic layer was observed which was metallurgically bonded to the steel substrate. No tungsten carbide phase was observed in this layer although a pearlitic zone in the steel was noted under the metallic layer. Indentation hardness values of 321 VHN to 362 VHN (200 g) were measured for the metallic layer.

The warpage of these samples was measured and reported in Appendix B. High warpage was observed for these 'thin' (0.063") substrates.

6. GLASS ON STEEL COATINGS

6.1. Substrate Thickness Effect On Warpage

The purpose of this trial was to assess the effect of substrate thickness on substrate warpage.

All samples in set 91 were coated with a slurry of Ferro XG684 porcelain enamel glass powder with a series of substrate thicknesses ranging from 1/16" to 1/2". The steel substrates used in this series ranged from 0.060" thick to 0.502" thick. All substrates were grit-blasted on one side and measured 4" x 8". All samples were moved through the Vortek lamp along it's length at 0.5 cm to 1.0 cm below the focus of the lamp's reflector. An air sweep across the lamp window was used to sweep away reaction gases and soot in all runs except for sample P87-1.

Selected samples of sintered glass and glass on cermet coatings were cut, mounted in epoxy, polished and metallurgically examined.

Values of warpage reported in Appendix B were measured by placing the sintered sample on a granite measurement base and measuring the high point on the sample. The height measured was then corrected for sample thickness (including coating) to yield a warpage value. The warpage results are presented in Figure 6.1.1. Data for sample set 91 was supplemented by data from set 103 for 0.25" thick substrates. These data indicate that the warpage is indeed reduced with thicker samples.

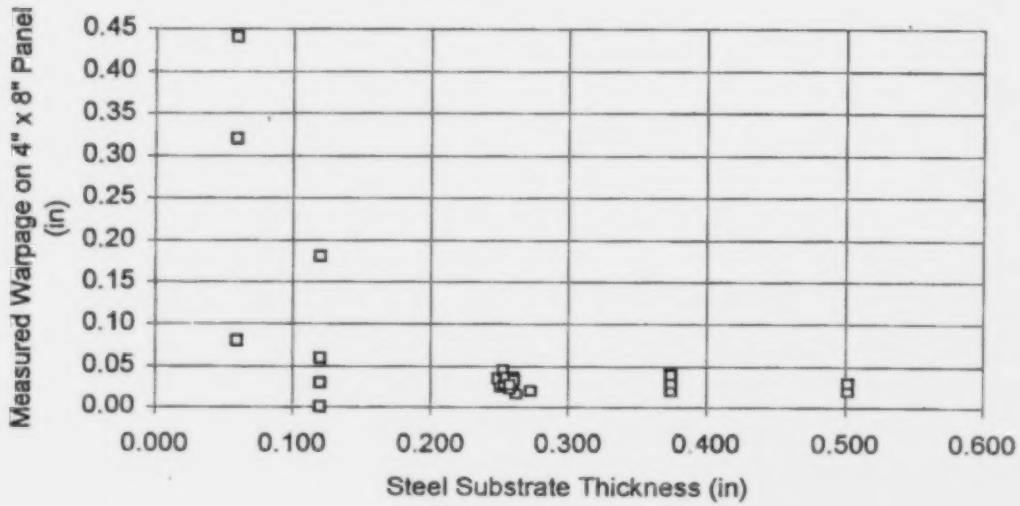

Figure 6.1.1 - Warpage as a Function of Thickness

Samples were cut for cross section examination. Both cross sections showed a continuous glass coating with residual porosity and non-uniform thickness. On sample P91-15 (3/8" thick) a heat affected zone was observed. The steel microstructure exhibited re-crystallization to a depth of approximately 0.050" from the coating interface. This indicates that this zone was exposed to temperatures in excess of 750°C to a depth of 0.050". A significant heat-affected zone was not observed for substrates 0.25" thick or less.

The coatings observed in this series were more severely 'beaded' as compared to previous trials in Phase I. It is postulated that the thicker glass layer absorbed more light energy and began to sinter while the thicker substrate caused a 'cooler' steel top surface. It was observed in Phase I that the steel surface must reach a

high temperature before the glass will wet the steel and flow into an even layer. If a bead of glass does not fully flow and remains a thick section of glass, the thermal expansion mismatch between the glass and steel will create sufficient stress to craze the glass bead off the steel. It appears that the thicker steel substrates used in this trial accentuated this problem.

6.2. Lower Binder Content Glass Coatings

The effect of lower organic binder content in the sprayed glass coating was investigated by the comparison of sample sets 94 and 98. The CAB binder content was reduced from 16.6 wt% for set 94 to 10 wt% for set 98. The sprayed coating thickness was higher in set 98 (set 94 at 3-8 mils and set 98 at 7-10 mils) with considerable variation in the sprayed coating thickness. Sets 94 and 98 were also used for lamp window air sweep trials by Vortek. Sintered sample data for both sets are included in Appendix B.

All of the samples in set 94 resulted in well-fused glass coatings while all the samples in set 98 resulted in beaded and spalled coatings at comparable lamp power levels at all air sweep rates. This is shown in Figures 6.2.1 and 6.2.2. The coating beading and spalling for set 98 could have been due to high power absorption due to reduced smoke or could be the result of a higher as sprayed film thickness. Subsequent data to this series has identified as-sprayed film thickness of <4 mils as being important to the reduction of beading and spalling.

Firm conclusions cannot be drawn from a comparison of these sample sets.

6.3. Coating Thickness Effect Series

Sample set 103 consisted of a series of samples with either 4-6 mils or 8-10 mils of as-sprayed glass coating containing 10 wt% CAB binder on 0.25" substrates. These samples were sintered at lamp current levels of 575 A, 650 A and 725 A at a series of lamp window air sweep levels (on, low and off). Sintered sample data are presented in Appendix B.

The results of this series are difficult to interpret definitively with respect to air sweep but a side by side comparison of samples processed under nominally identical conditions indicated that there was less beading and greater glass coating adhesion with 4-6 mil coatings as compared to 8-10 mil as-sprayed coatings at all

three lamp power levels. Coatings sintered at 575 A were slightly under-fused while coatings sintered at 725 A were usually over-heated except for those sections with obvious carbon deposits.

A second comparison of sample sets was performed in sample set 114. This set of samples included thinner and thicker as-sprayed samples as well as nickel flashed/coated substrates (discussed in section 8). Sample set 114 consisted of 0.25" thick substrates with XG684/10 wt% CAB 381.01 binder at as-sprayed coating thicknesses of approximately 4 mils or 8 mils. Sample sintering data is included in Appendix B.

The comparison of sintered 4 mil and 8 mil as-sprayed coatings is dramatic as shown in Figures 6.3.1 and 6.3.2. The sample (Figure 6.3.1) with the as-sprayed coating thickness of 4 mils was smooth, well fused to the substrate and not beaded. The sample (Figure 6.3.2) with the as-sprayed coating thickness of 7.5 mils was beaded and well fused to the substrate. The beading was not severe enough to result in spalling of the glass coating upon cooling.

The success of achieving smooth sintered glass coatings appears to be directly linked to as-sprayed coating thickness. As-sprayed coating thickness of less than 4 mils is desirable.

The sintered coating was reduced to approximately half of the as-sprayed coating thickness as shown in figure 6.3.3. Figure 6.3.3 is an optical micrograph of an epoxy mounted, polished cross section through the upper surface of sample 114-2 at 100X magnification. A fused glass layer 2.5 mils thick is observed with spherical porosity (from gas trapped in the glass coating). The glass coating is well bonded to the steel substrate. A significant heat affected zone is not observed nor is the presence of a pearlite phase at the steel surface. This would indicate a clean burnout of the CAB binder during coating sintering.

7. CERMET ON STEEL COATINGS

Although most of the samples prepared in this phase were based on glass coatings, a major focus is self-fluxed cermet coatings based on Metco 34F powder. Glass coatings are easier to control for process development purposes. However, the

process development knowledge learned with glass coatings can be adapted to cermet coatings.

Sample set 96 consisted of a series of samples on 0.25" grit-blasted steel plates spray coated with 6-10 mils of Metco 34F cermet powder with 16.6 wt% Elvanol binder. Sintering results are presented in Appendix B.

Sample set 115 consisted of a series of samples on 0.25" grit-blasted steel plates spray coated with 3-4 mils of Metco 34F cermet powder with 5 wt% Elvanol binder. Some of the steel plates were nickel flashed or plated. Sintering results are presented in Appendix B.

A sample from set 96 is presented in Figure 7.1 and a sample from set 115 is presented as Figure 7.2. Several key items should be noted:

- The lamp power required to sinter the coating to the steel substrate is slightly higher for 34F coatings (approximately 725 A versus approximately 600 A for XG684 glass);

- Substrate warpage is slightly higher for cermet coatings than glass coatings (warpage of approximately 0.030" for XG684 glass and approximately 0.060" for 34F on a 4" x 8 " panel);

- The reduction in the as-sprayed coating thickness from 7-10 mils to 3-4 mils is not as beneficial as with glass coatings;

- Carbon formation from the binder is reduced but still apparent when the binder is reduced from 16.6 wt% to 5 wt%. The volume percent binder in the as-sprayed coating is considerably higher with cermet coatings than glass coatings due to the much higher density of the cermet as compared to glass. At 5 wt% binder levels, the volumetric fraction of the binder in the coating is comparable but still higher than for 16.6 wt% binder in glass coatings.

Cross sections of samples in set 115 were mounted in epoxy, polished and etched to reveal the metal microstructure. The cermet coating was fused to the steel substrate and metallurgically bonded. Figure 7.3 (100X) and Figure 7.4 (400X) demonstrate the excellent metallurgical bond to the steel substrate. The presence of a pearlitic phase immediately under the fused cermet particles is indicated by the

dark grains, most evident in Figure 7.4. Some porosity, indicating an incomplete bonding of the cermet to the steel, was apparent in other parts of the cross section.

It is apparent from Figure 7.3 that cermet beads are formed during lamp sintering and these beads fuse to the steel surface. A space between two of these fused beads is evident in Figure 7.3 with carbonaceous material in the space between the fused beads. Carbide particles are apparent in the fused cermet coating. This gap would allow water to penetrate to the surface of the steel and reduce corrosion resistance. Nickel-coated steel, as discussed in section 9, deals with this issue of pore penetration through the coating.

The data generated by samples in set 115 indicate that self-bonded cermet coatings can be effectively applied to steel substrates with minimal warpage but that a continuous cermet coating is difficult to achieve. The continuity of the cermet coating is not a key factor in abrasive wear situations and the key factors are coating hardness/toughness in conjunction with the strength of the bond between the coating and the substrate (to avoid delamination or spalling of the coating). Coating continuity is important for corrosion situations as the cermet coating will be more corrosion resistant than the steel substrate.

8. NICKEL COATED SUBSTRATES

One of the purposes of this trial was to assess whether the steel substrate was oxidizing and inhibiting wetting of glass during lamp sintering. In order to reduce surface oxidation, a series of steel substrates was coated with electroless nickel. A total of nine steel substrates were nickel coated. An additional benefit of nickel plating the steel substrate would to be to render the substrate far more corrosion resistant. Flaws or other discontinuities in the cermet coating could be tolerated if the nickel flash or plating was sufficiently corrosion resistant.

Three 4" x 8" x 0.25" samples were electroless nickel-plated on the grit-blasted surface to a coating thickness estimated to be 5 mils. The remaining 6 of 4" x 8" x 0.25" samples were electroless nickel plated on the grit-blasted surface to a coating thickness estimated to be 0.5 mils.

The non-grit-blasted sides of the panels were masked with electroplater's tape and the panels were degreased using acetone. Prior to plating, each panel was cleaned by immersion in a 20% sodium hydroxide solution for two minutes and rinsed with deionized water. Next, the surface to be plated was dipped for about five seconds in the activating solution provided with the proprietary two component electroless nickel plating solution used (Struers 'Hard Coat') and rinsed with deionized water. The panel was then immersed with the surface to be plated facing upwards in the plating solution which was maintained at 85-95°C for either 3 minutes or 30 minutes for the flash or thick deposit, respectively. These times were selected to give a theoretical thickness of 0.5 µm for the flash deposit and 5 µm for the thick deposit.

Sintering results are included in Appendix B.

No definitive effect of nickel coating (flash or plated) was noted upon examination after lamp sintering. However, after the samples had been cut with a water cooled abrasive wheel for cross sections, it was noted that there were rust spots evident on the non-nickel treated samples whereas no rust was evident for those samples treated with nickel (flash or plate).

Nickel treated steel substrates (flash or plate) were included in set 114 prepared with XG684 glass coatings. No definitive effect of nickel surface treatment was observed for glass coated samples.

9. AIR SWEEP TRIALS

Lamp trials at Vortek were undertaken to evaluate various aspects of the lamp sintering process. One of these process factors was the use of an air sweep across the face of the fused silica window of the reflector chamber. Normally, the air sweep is used to prevent debris from depositing on the fused silica window, but in this case it also served to blow smoke and fumes away from the lamp beam.

Visual examination of air sweep trial samples for sets 94, 98 and 103 indicated that the air sweep usually reduced the total amount of residual carbon but did not eliminate carbon deposits on the sintered samples nor was residual carbon deposition consistent from run to run.

10. CONCLUSIONS

1. Self fluxed cermet (Metco 34F) coatings have been prepared on 0.25" thick steel panels by Vortek lamp sintering. These cermet coatings were metallurgically bonded to the steel substrate.

2. Porcelain enamel (Ferro XG684) glass coatings have been prepared on 0.25" thick steel panels by Vortek lamp sintering. The glass coatings were well bonded to the steel substrate. Residual carbonaceous char from the decomposition of organic binders was present in both glass and cermet coatings if an organic binder was used.

3. Complete coverage of the surface (i.e. without holes through the coating) has not been achieved for cermet coatings. Coating the steel substrate with a nickel flash or plating improved the resistance of the substrate to corrosive attack through the flaws in the cermet coating.

4. The thickness of the steel substrate greatly affects the amount of warpage caused by lamp sintering. Low warpage of 0.025" thick x 4" x 8" steel panels was typically observed for both XG684 glass (usually 0.020" to 0.040") and for Metco 34F self-fluxing cermet coatings (usually 0.040" to 0.080"). Panels thicker than 0.25" warped slightly less than the 0.25" panels.

5. Panels 0.25" or less in thickness did not exhibit significant heat affected zones on the top surface of the steel panels. Heat affected zones of up to 0.050" were observed for 0.375" and 0.5" thick samples.

6. All organic binders used in this program produced significant quantities of smoke and char during lamp sintering. Carbonaceous residue was always present from coatings containing organic binder to some degree or another. The decomposed organic binder often promoted the formation of a carbon rich (pearlitic) phase on the surface of the steel under the cermet coating.

7. Thin as-sprayed coatings (<0.004") were superior to thick coatings with respect to coating quality and coverage on the substrate. It is postulated that the light energy absorbed in the thicker coatings causes the coating to sinter together and separate from the steel substrate. Once separated from the substrate, the coating melts into beads. If the substrate surface is heated sufficiently, the beads can wet the steel surface and bond to it. If the steel substrate does not achieve a sufficiently high temperature, the glass or cermet coating will not bond to the substrate.

8. The use of sodium silicate as an inorganic binder for glass exhibited significant potential for producing smooth, well bonded glass surfaces. Smoke generation was drastically reduced.

D. M. Camm
Vice President
Technology Development

11. FIGURES

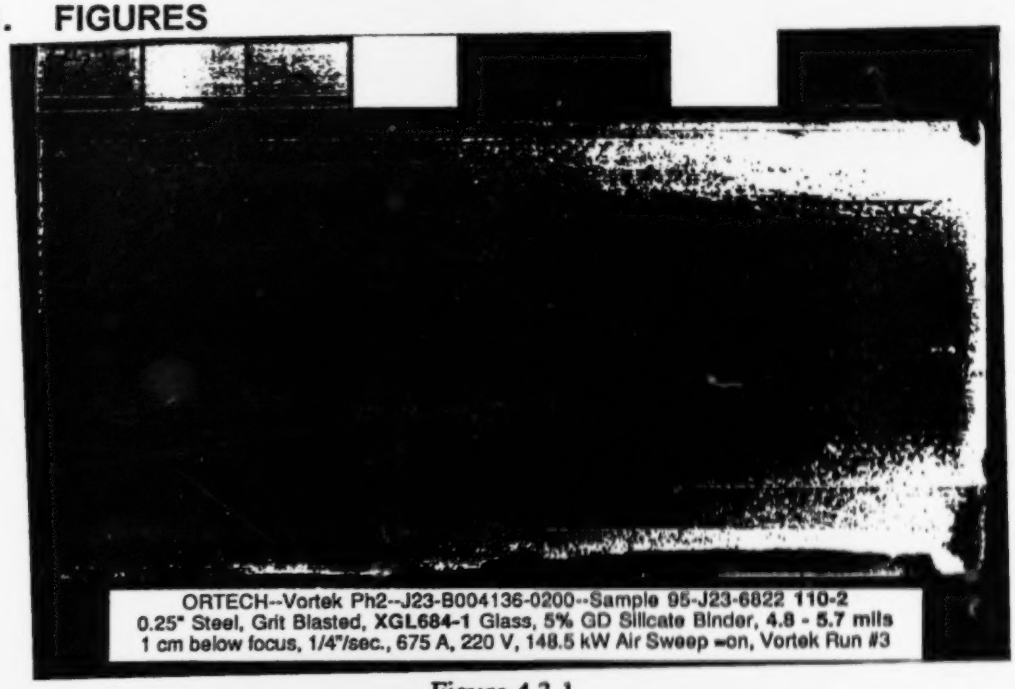
ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6822 110-2
0.25" Steel, Grit Blasted, XGL684-1 Glass, 5% GD Silicate Binder, 4.8 - 5.7 mils
1 cm below focus, 1/4"/sec., 675 A, 220 V, 148.5 kW Air Sweep =on, Vortek Run #3

Figure 4.3.1
5% Sodium Silicate Addition Sintered At 675A

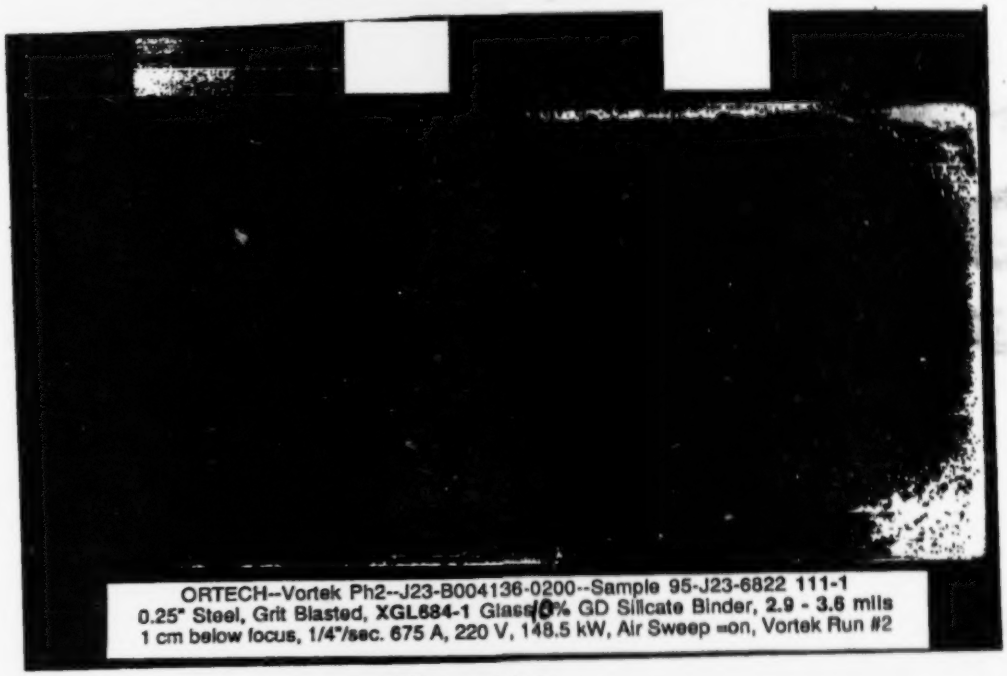
ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6822 111-1
0.25" Steel, Grit Blasted, XGL684-1 Glass, 10% GD Silicate Binder, 2.9 - 3.6 mils
1 cm below focus, 1/4"/sec. 675 A, 220 V, 148.5 kW, Air Sweep =on, Vortek Run #2

Figure 4.3.2
10% Sodium Silicate Addition Sintered At 675A

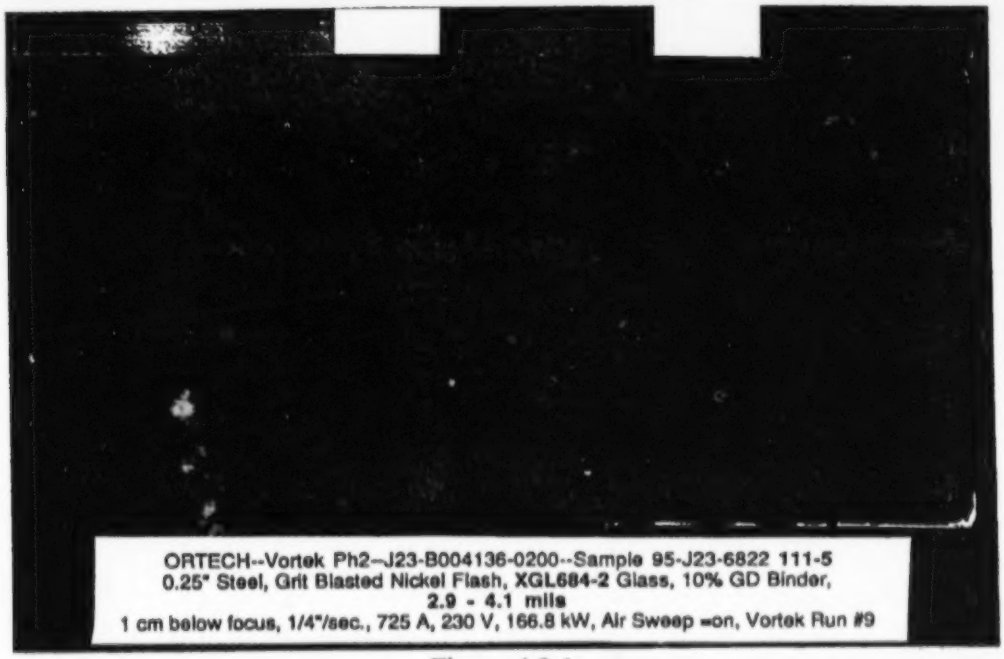
ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6822 111-5
0.25" Steel, Grit Blasted Nickel Flash, XGL684-2 Glass, 10% GD Binder,
2.9 - 4.1 mils
1 cm below focus, 1/4"/sec., 725 A, 230 V, 166.8 kW, Air Sweep =on, Vortek Run #9

Figure 4.3.1
3-4 mil Thick 10% Sodium Silicate Addition Sintered At 725A

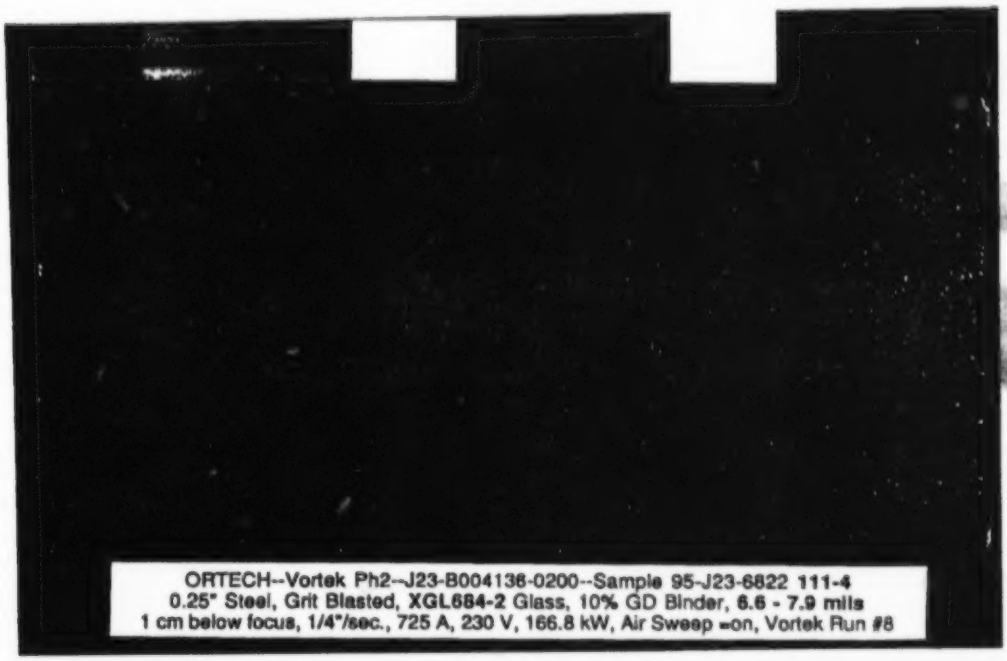
ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6822 111-4
0.25" Steel, Grit Blasted, XGL684-2 Glass, 10% GD Binder, 6.6 - 7.9 mils
1 cm below focus, 1/4"/sec., 725 A, 230 V, 166.8 kW, Air Sweep =on, Vortek Run #8

Figure 4.3.2
6-8 mil Thick 10% Sodium Silicate Addition Sintered At 725A

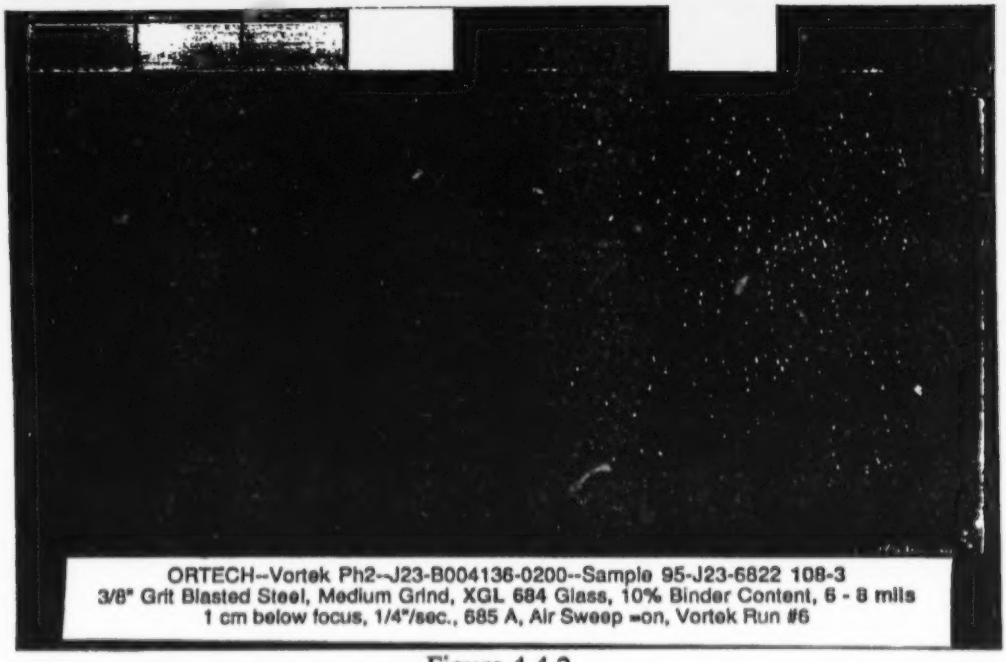
ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6822 108-3
3/8" Grit Blasted Steel, Medium Grind, XGL 684 Glass, 10% Binder Content, 6 - 8 mils
1 cm below focus, 1/4"/sec., 685 A, Air Sweep =on, Vortek Run #6

Figure 4.4.2
6-8 mil 'Medium Grind' XG684 On 3/8" Steel Sintered At 685 A

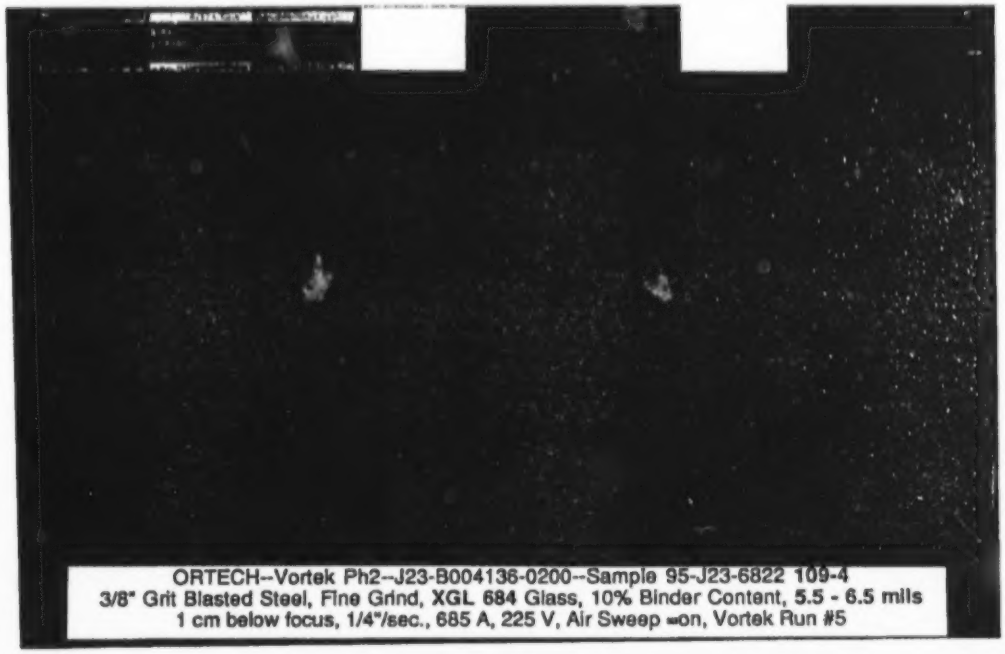
ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6822 109-4
3/8" Grit Blasted Steel, Fine Grind, XGL 684 Glass, 10% Binder Content, 5.5 - 6.5 mils
1 cm below focus, 1/4"/sec., 685 A, 225 V, Air Sweep =on, Vortek Run #5

Figure 4.4.3
6-8 mil 'Fine Grind' XG684 On 3/8" Steel Sintered At 685 A

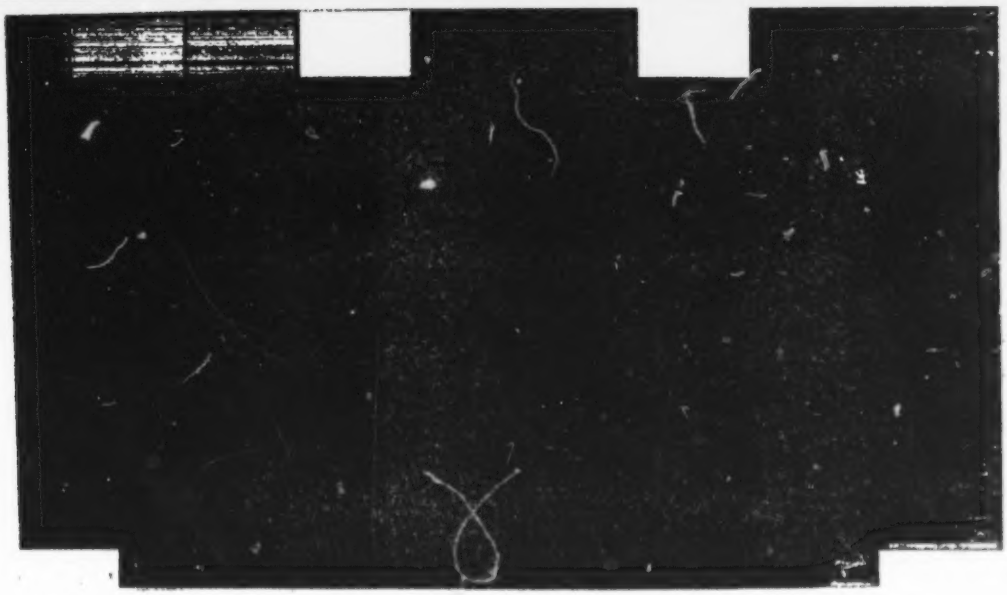

Figure 5.1
Typical Lamp Sintered Dual Coated Panel

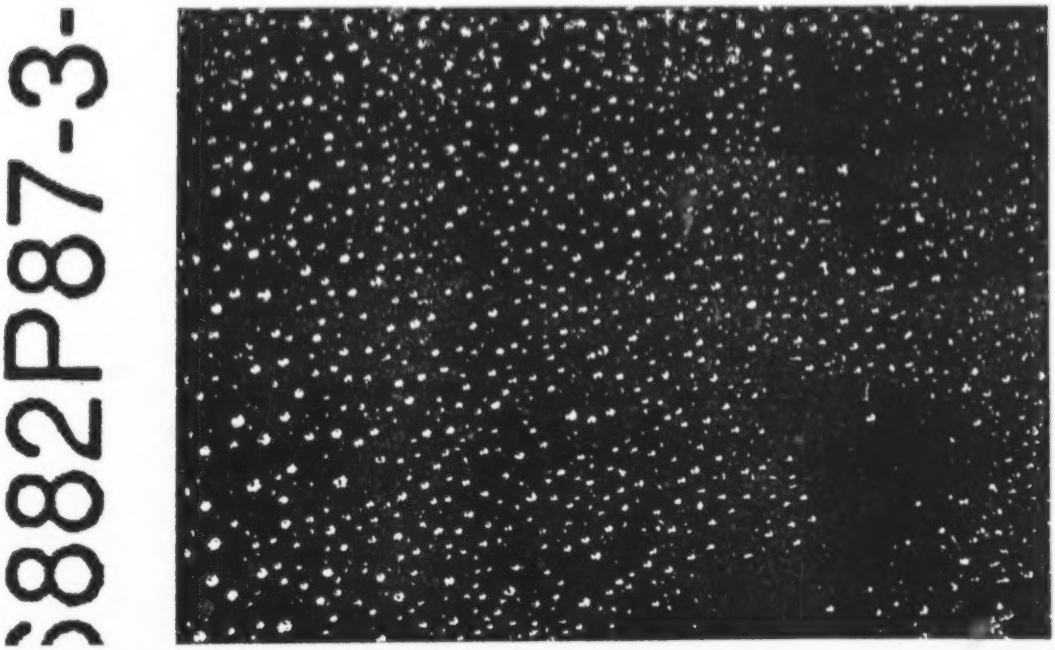

Figure 5.2
Close-up Of Typical Lamp Sintered Dual Coated Panel

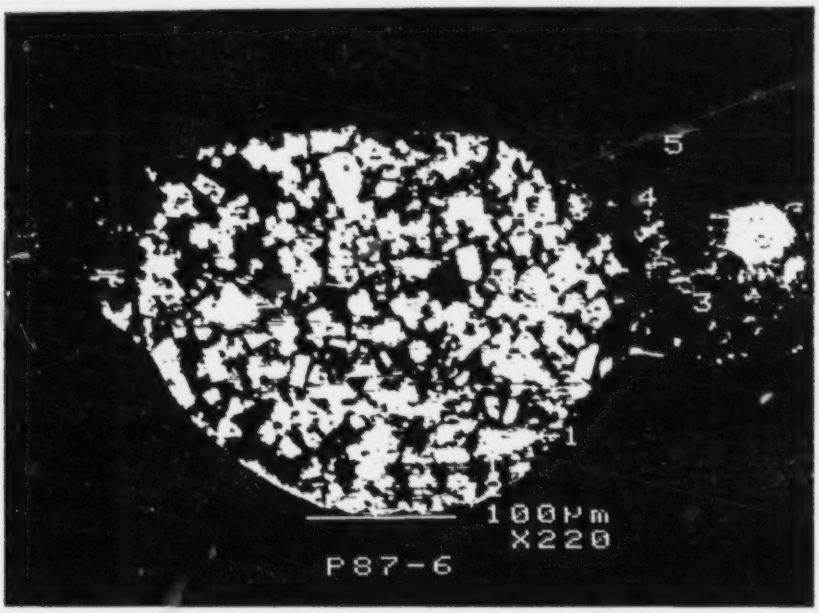

Figure 5.3
SEM Of Cross Section Of A Cermet Bead Bonded To The Steel Substrate

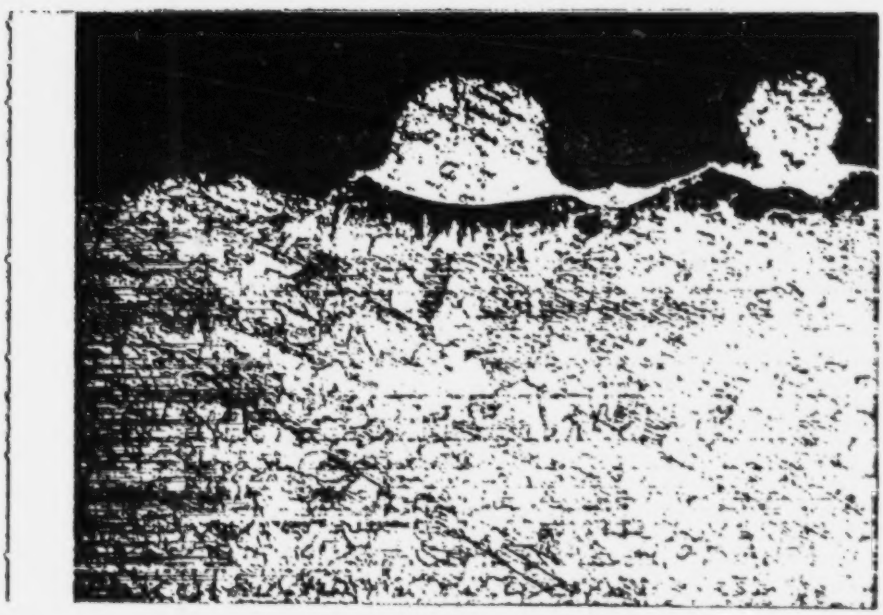

Figure 5.4
Optical Micrograph Of Cross Section Of A Cermet Bead
(etched, 100X)

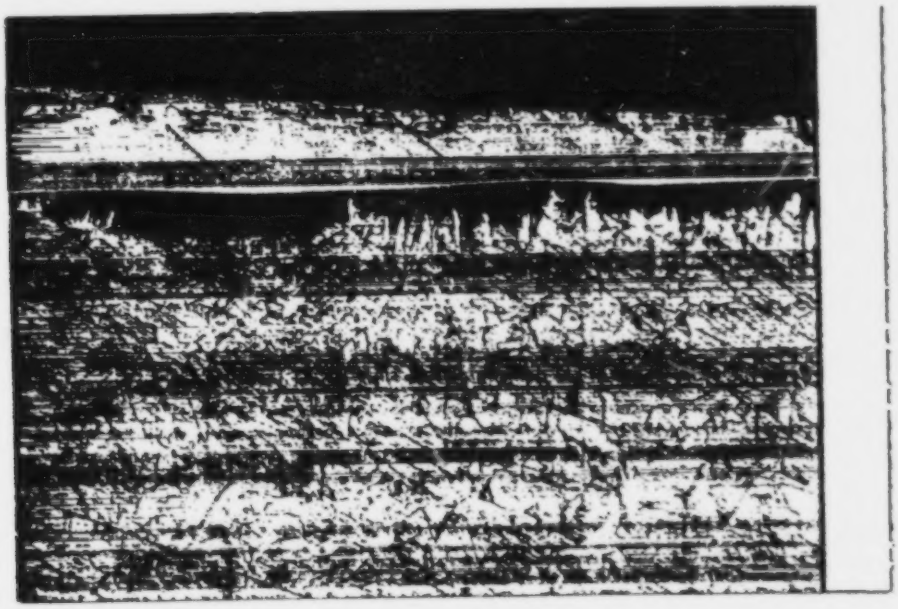

Figure 5.5
Optical Micrograph Of Cross Section Of Metallic Layer (P87-5)
(etched, 100X)

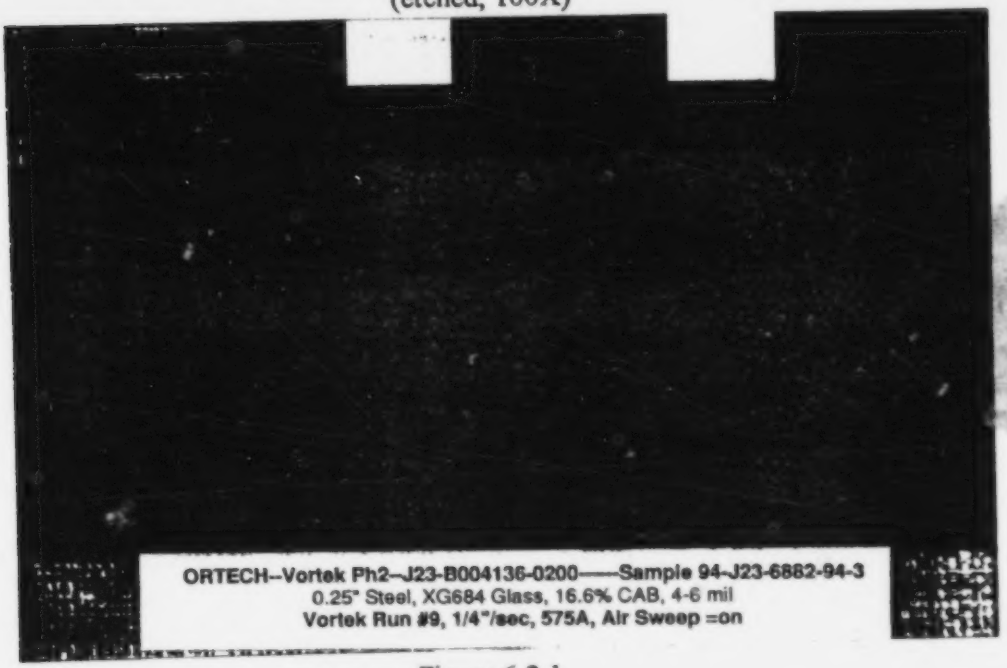
ORTECH--Vortek Ph2--J23-B004136-0200----Sample 94-J23-6882-94-3
0.25" Steel, XG684 Glass, 16.6% CAB, 4-6 mil
Vortek Run #9, 1/4"/sec, 575A, Air Sweep =on

Figure 6.2.1
4-6 mil 16.6 wt% CAB/XG684 (Set 94) Sintered At 575 A

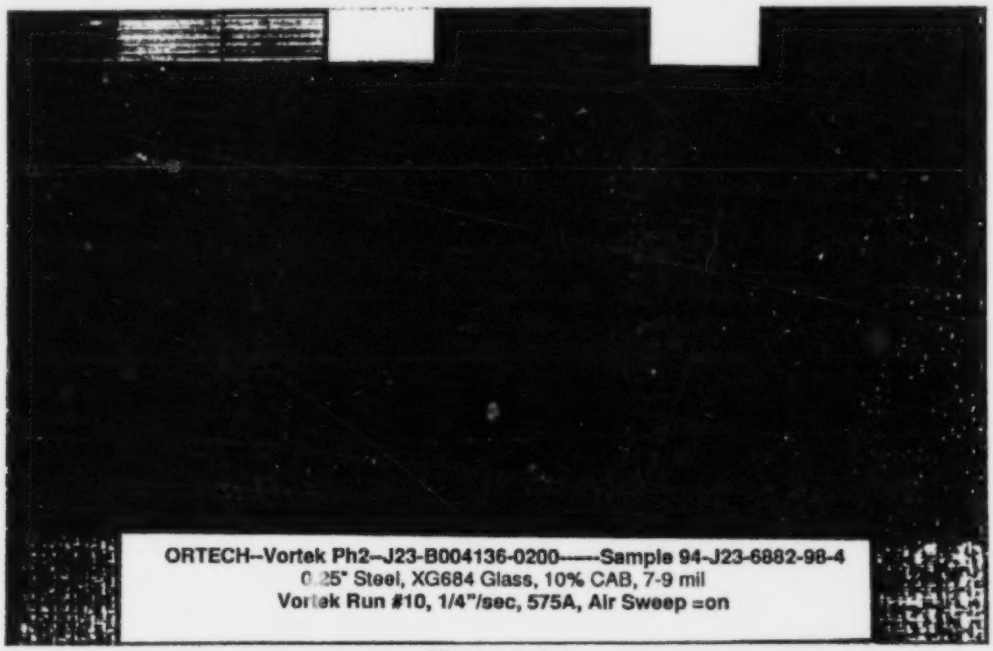
ORTECH--Vortek Ph2--J23-B004136-0200-----Sample 94-J23-6882-98-4
0.25" Steel, XG684 Glass, 10% CAB, 7-9 mil
Vortek Run #10, 1/4"/sec, 575A, Air Sweep =on

Figure 6.2.2
7-9 mil 10 wt% CAB/XG684 (Set 98) Sintered At 575 A

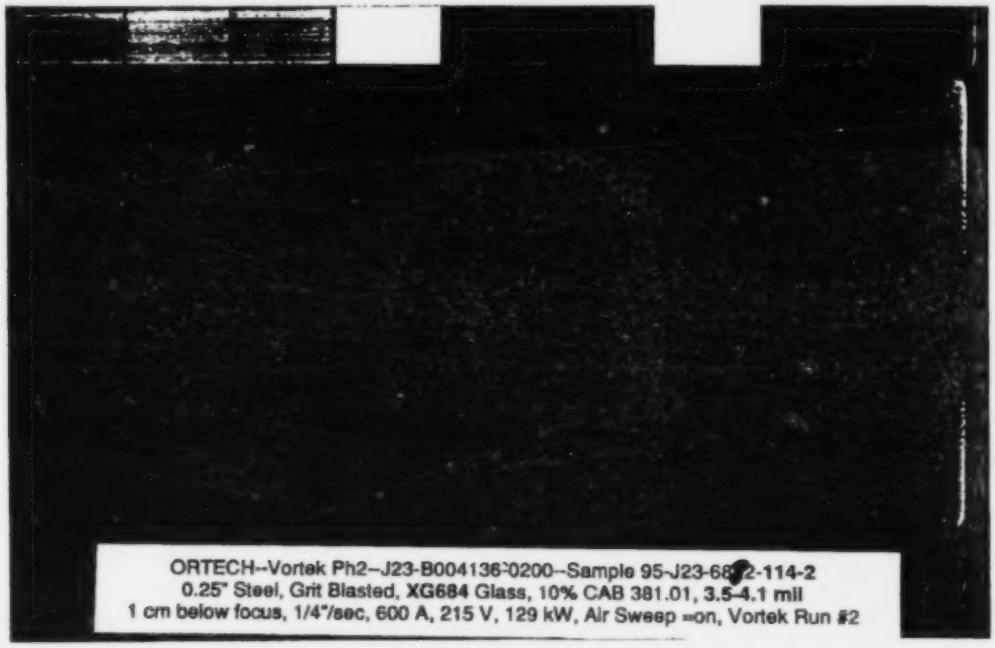
ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6882-114-2
0.25" Steel, Grit Blasted, XG684 Glass, 10% CAB 381.01, 3.5-4.1 mil
1 cm below focus, 1/4"/sec, 600 A, 215 V, 129 kW, Air Sweep =on, Vortek Run #2

Figure 6.3.1
4 mil 10 wt% CAB/XG684 (Sample 114-2) Sintered At 600 A

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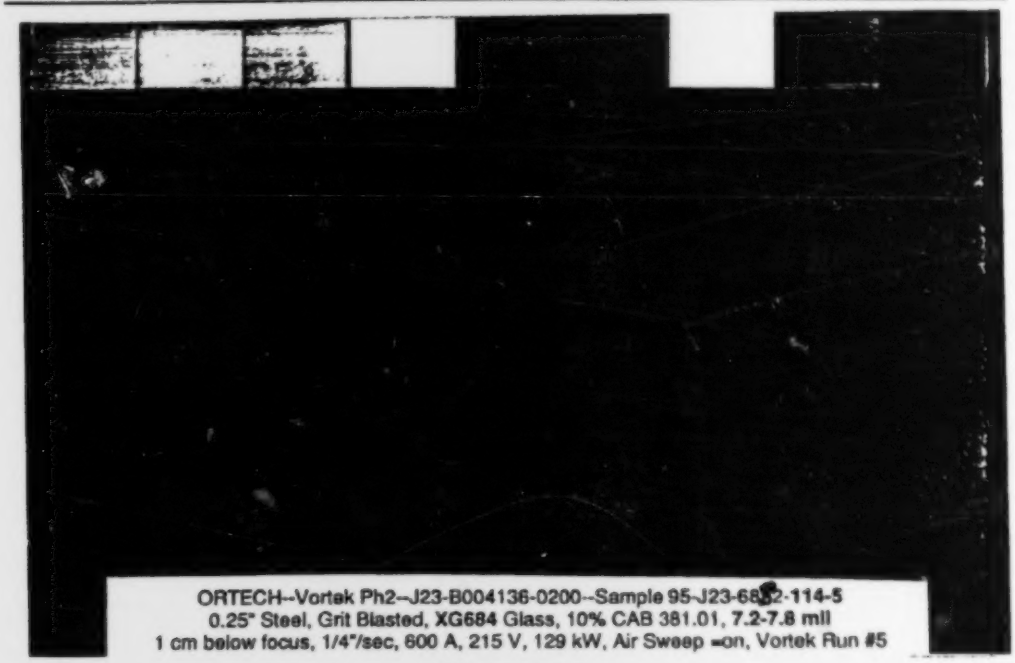

ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6852-114-5
0.25" Steel, Grit Blasted, XG684 Glass, 10% CAB 381.01, 7.2-7.8 mil
1 cm below focus, 1/4"/sec, 600 A, 215 V, 129 kW, Air Sweep =on, Vortek Run #5

Figure 6.3.2
7.5 mil 10 wt% CAB/XG684 (Set 114) Sintered At 600 A

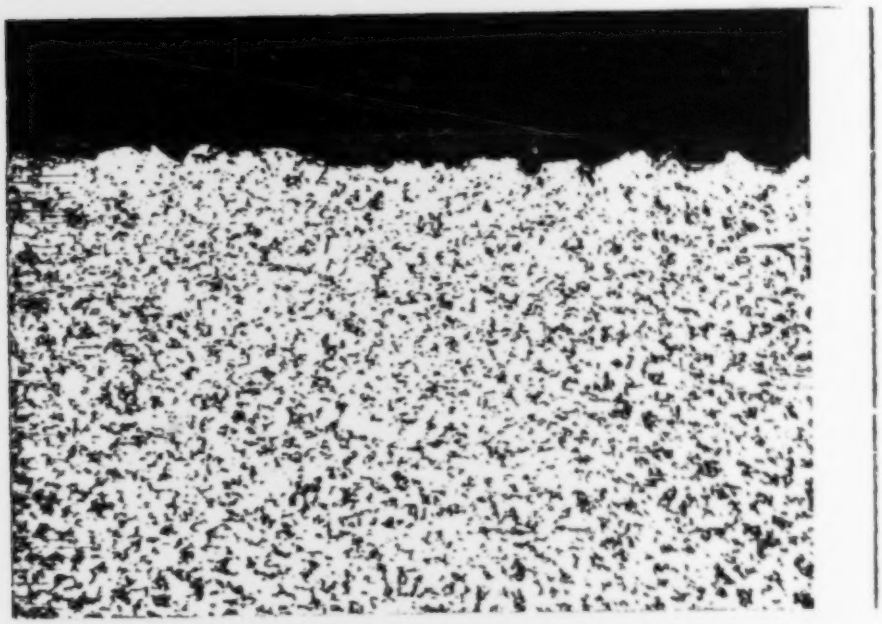


Figure 6.3.3
Optical Micrograph Of Cross Section Through Sample 114-2
(Etched, 100X)

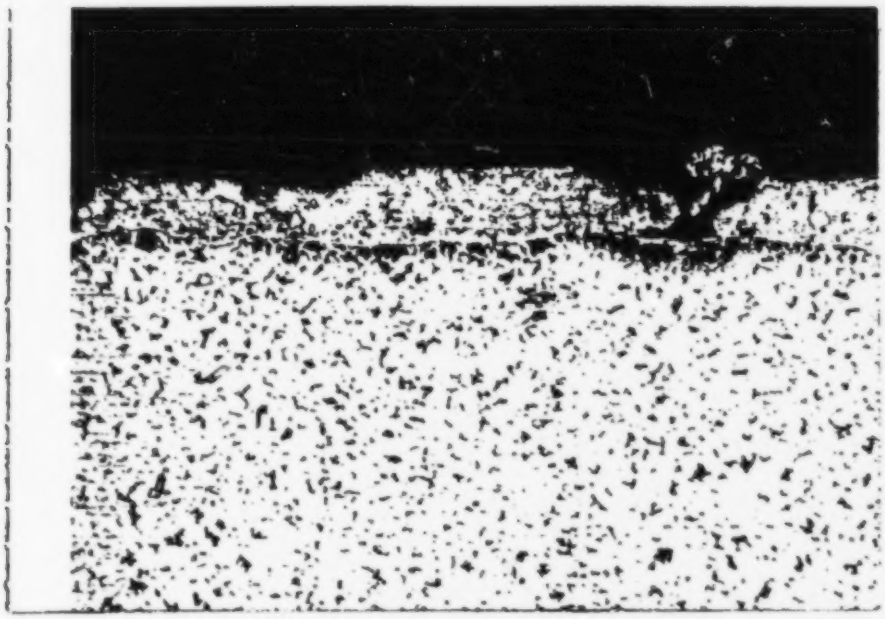


Figure 7.1
6-9 mil 16.6 wt% Elvanol (Sample 96-2) Sintered At 725 A

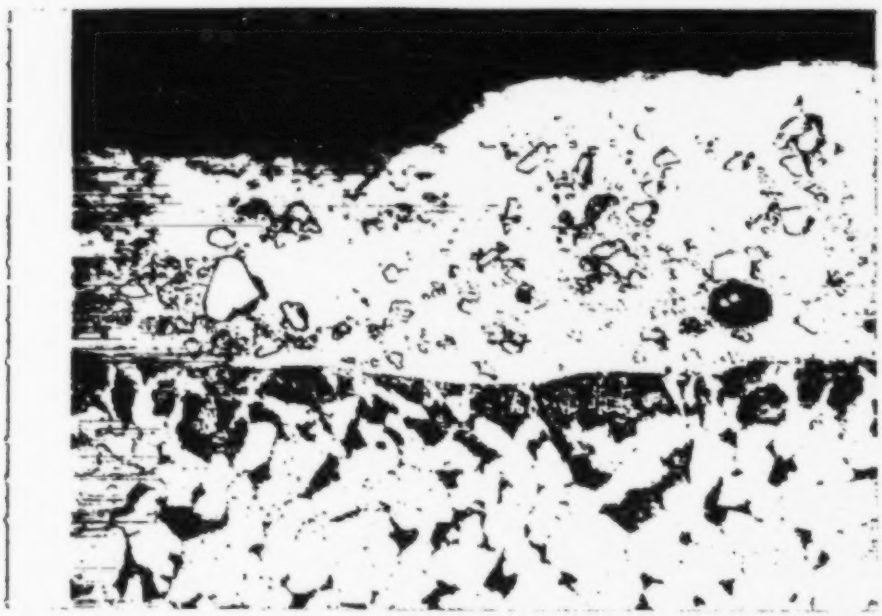


Figure 7.2
3-4 mil 5 wt% Elvanol (Sample 115-4) Sintered At 725 A

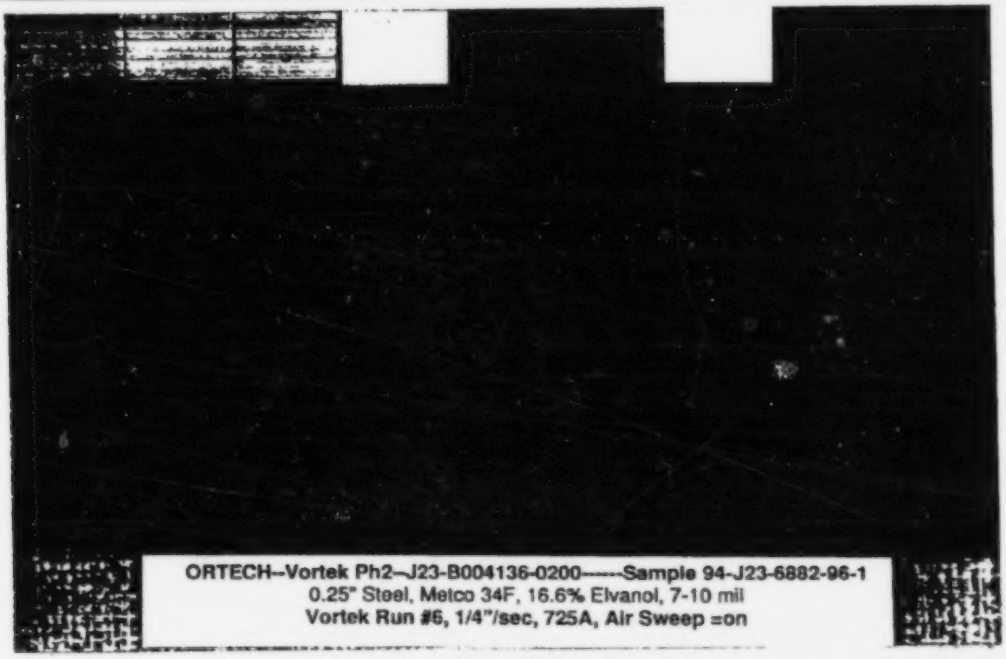

ORTECH--Vortek Ph2--J23-B004136-0200-----Sample 94-J23-6882-96-1
0.25" Steel, Metco 34F, 16.6% Elvanol, 7-10 mil
Vortek Run #6, 1/4"/sec, 725A, Air Sweep =on

Figure 7.3
Optical Micrograph Of Cross Section Through Sample 115-4
(Etched, 100X)

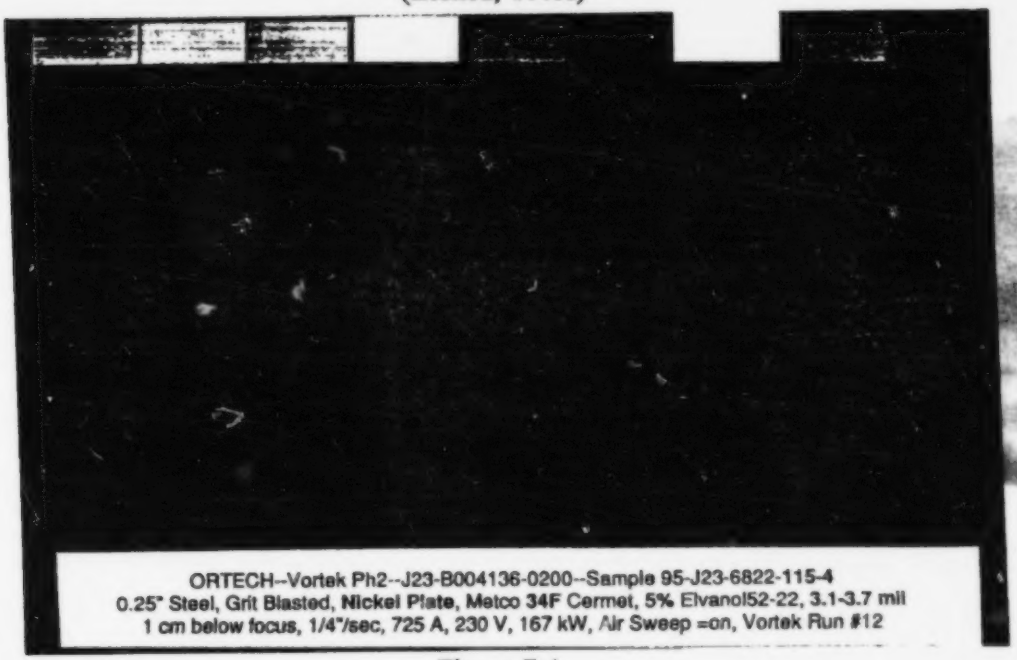

ORTECH--Vortek Ph2--J23-B004136-0200--Sample 95-J23-6822-115-4
0.25" Steel, Grit Blasted, Nickel Plate, Metco 34F Cermet, 5% Elvanol52-22, 3.1-3.7 mil
1 cm below focus, 1/4"/sec, 725 A, 230 V, 167 kW, Air Sweep =on, Vortek Run #12

Figure 7.4
Optical Micrograph Of Cross Section Through Sample 115-4
(Etched, 400X)

12. Appendix A: Pre-Sintered Sample Data

CAB-Based Topcoat Formulation

Prepare the following intermediates:

(Paste 1 and CAB Solution 1)

Paste 1

Preblend the following and grind on a ball mill until a Hegman 7.5 grind is obtained:

XG684	82.6
CAB 381.1	0.8
Acetone	16.6

CAB Solution 1

Dissolve the following with a high speed mixer:

CAB 381.01	21.0
Acetone	79.0

Glass Topcoat

Paste 1	299.5
CAB Solution 1	213.7
Acetone	67.0
PM Acetate	17.0
	597.2

Elvanol-Based Basecoat Formulation

Prepare the following the intermediate:

Elvanol Solution 1

Mix at low speed until dissolved:

Elvanol 51-05	22.9
Water	77.1

Metco Basecoat

Add the following and mix on a high speed disperser:

Elvanol Solution 1	44.0
Metco 34F	200.0
Disperbyk 130	0.3

Reduce to spray viscosity (18" - 24 " Ford 4 cup)

Water	93.0
n-Butanol	23.0
	360.3

13. Appendix B: Sintered Sample Data

Table B.1
Glass On Cermet Sintered Specimens (Sept. 26/94-Oct. 2/94 Series)
(* all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Warpage Material	Lamp Current (A)	Substrate Speed (in/sec)	Steel Thickness (inches)	Observed (inches)
P87-1	Base of XG684 Glass (6-8 mils); plus 34F Cermet (9-14 mils total)	750	1.0	0.063	0.22
		Cermet fused into beads, glass fused adherent glass coverage not complete			
P87-2	Base of XG684 Glass (6-8 mils); plus 34F Cermet (8-11 mils total)	800	1.0	0.063	0.20
		Cermet fused into beads, glass fused glass coverage good but not complete			
P87-3	Base of XG684 Glass (6-8 mils); plus 34F Cermet (7-11 mils total)	500	0.55	0.063	0.57
		Cermet fused as smaller beads (vs 1 or 2) glass fused, coverage almost complete			
P87-4**	Base of XG684 Glass (5-8 mils); plus 34F Cermet (7-11 mils total)	600	0.55	0.063	0.24
		Much more 'glassy in appearance cermet fused into beads as per 3 glass fused, coverage almost complete			
P87-5**	Base of XG684 Glass (5-7 mils); plus 34F Cermet (8-10 mils total)	700	0.55	0.063	0.32
		centre: mostly oxidized with metallic patches front, back & side sections: glassy with small cermet beads as per 4			
P87-6**	Base of XG684 Glass (5-7 mils); plus 34F Cermet (7-10 mils total)	650	0.55	0.063	0.26
		centre: glassy areas with dull oxide patches some metallic patches as well front, back & side sections: as per 4			
P87-7	Base of XG684 Glass (5-8 mils); plus 34F Cermet (8-11 mils total)	625	0.55	0.063	0.94
		centre: dull oxide with (larger) glassy or metallic patches one side: as per 4			

** cross-sectioned in one area for microscopy

Table B.2
Glass Coated Specimens (Sept. 26/94-Oct. 2/94 Series)
(* all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Warpage Material	Lamp Current (A)	Substrate Speed (in/sec)	Steel Substrate Size	Observed (inches)
P91-21	XG684 Glass (5-10 mils)	375	0.5	0.060"x4"x8"	na
		Coating did not adhere and flaked off			
P91-23	XG684 Glass (8-15 mils)	400	0.5	0.060"x4"x8"	0.08
		Coating did not adhere and flaked off			
P91-22	XG684 Glass (6-11 mils)	425	0.5	0.060"x4"x8"	0.32
		Centre: coating flaked off, appears oxidized, very little fusion to steel Front & back sections: glass fused as beads			
P91-24	XG684 Glass (8-15 mils)	450	0.5	0.060"x4"x8"	0.44
		Centre: coating flaked off Front, back & sides: glass fused as beads and partially fused to steel, most popped off			
P91-20	XG684 Glass (6-10 mils)	675	0.5	0.120"x4"x8"	0.06
		Centre: glass fused as beads Front, back & sides: glass fused as large beads and partially fused to steel, most popped off			
P91-17	XG684 Glass (8-15 mils)	715	0.5	0.120"x4"x8"	0.03
		Centre: beads flaked off, oxidized/thin glass mottled coat Front, back & sides: glass fused as large beads and partially fused to steel, most popped off			
P91-18	XG684 Glass (8-15 mils)	475	0.25	0.120"x4"x8"	0.00
		Centre: oxidized, coating flaked off Front, back: glass fused Sides: glass fused as beads, most popped off			
P91-19**	XG684 Glass (5-10 mils)	525	0.25	0.120"x4"x8"	0.18
		Best sample. Beads fused to steel surface but not complete coverage, small mottled areas oxidized			

** cross-sectioned in one area for microscopy

Table B.2 (Continued)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Current (A)	Substrate Speed (in/sec)	Steel Substrate Size	Observed Warpage (inches)
P91-13	XG684 Glass (6-9 mils)	600	0.25	0.375"x4"x8"	0.02
		Centre: glass fused as beads which flaked off Mid-section, front & back: beads fused to surface Sides: glass fused as beads which flaked off			
P91-14	XG684 Glass (5-10 mils)	650	0.25	0.375"x4"x8"	0.03
		Centre: glass fused as beads which flaked off Mid-section, front & back: beads fused to surface Sides: glass fused as beads which flaked off Coating is more fused than 13			
P91-15**	XG684 Glass (4-9 mils)	700	0.25	0.375"x4"x8"	0.03
		Centre: glass fused as beads, some flaked off Mid-section, front & back: beads fused to surface Sides: glass fused as beads, some flaked off Much more of coating is adhering than 14			
P91-16	XG684 Glass (4-10 mils)	700	0.25	0.375"x4"x8"	0.04
		Centre: glass fused as beads, some flaked off, oxidized between beads Mid-section, front & back: beads fused to surface Sides: glass fused as beads, some flaked off, thin glassy appearance between flaked-off beads Less of coating is adhering than 15, more than 14			
P91-9	XG684 Glass (5-8 mils)	900	0.25	0.502"x4"x8"	0.02
		Centre: glass fused as larger beads, most flaked off, Front, back & sides: as per centre but more beads fused to steel, most popped off (run at 0.5 cm below focus)			
P91-10	XG684 Glass (5-10 mils)	900	0.25	0.502"x4"x8"	0.03
		Centre: glass fused as larger beads, half popped off Front, back & sides: as per centre but more beads fused to steel, oxidized between fused beads (run at 1.0 cm below focus)			

** cross-sectioned in one area for microscopy

Table B.3
Set 94: XG684 Glass/16.6 wt% CAB Coated Specimens
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Current (A)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
P94-1	XG684/16.6%CAB (4-8 mils)	525	0.25	0.25	na
P94-2	XG684/16.6%CAB (4-8 mils)	525	0.25	0.25	na
P94-3	XG684/16.6%CAB (4-8 mils)	525	0.25	0.25	na
P94-4	XG684/16.6%CAB (4-8 mils)	525	0.25	0.25	na

Table B.4
Set 96: Metco 34F Cermet/16.6 wt% Elvanol Coated Specimens
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Current (A)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
P96-1	34F/16.6%Elvanol (7-10 mils)	725	0.25	0.25	na
P96-2	34F/16.6%Elvanol (6-9 mils)	850	0.25	0.25	na
P96-3	34F/16.6%Elvanol (6-9 mils)	760	0.25	0.25	na
P96-4	34F/16.6%Elvanol (6-9 mils)	750	0.25	0.25	na

Table B.5

Set 98: XG684 Glass/10 wt% CAB Coated Specimens
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Current (A)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
98-1	XG684/10%CAB (8-10 mils)	550	0.25	0.25	na
98-2	XG684/10%CAB (8-10 mils)	600	0.25	0.25	na
98-3	XG684/10%CAB (8-10 mils)	650	0.25	0.25	na
98-4	XG684/10%CAB (7-9 mils)	575	0.25	0.25	na

Table B.6

103 Set: XG684 Glass/10 wt% CAB Coated Specimens
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
103-1 (Vor#1)	XG684/10%CAB (8-10 mils)	575A 200V	0.25 Air sweep on	0.25	.028
103-2 (Vor#2)	XG684/10%CAB (8-10 mils)	650 210V	0.25	0.25	.016
103-3 (Vor#9)	XG684/10%CAB (8-10 mils)	725 222V	0.25	0.25	.045
103-4 (Vor#16)	XG684/10%CAB	725 (8-10 mils)	0.25 222V	0.25	.038
103-5 (Vor#3)	XG684/10%CAB (4-6 mils)	575 200V	0.25	0.25	.025
103-6 (Vor#4)	XG684/10%CAB (4-6 mils)	650A 210V	0.25	0.25	.036
103-7 (Vor#10)	XG684/10%CAB	725A (4-6 mils)	0.25 222V	0.25	.029
103-8 (Vor#15)	XG684/10%CAB	725A (4-6 mils)	0.25 222V	0.25	.036
103-9 (Vor#5)	XG684/16.6%CAB (8-10 mils)	575A 200V	0.25	0.25	.023
103-10 (Vor#6)	XG684/16.6%CAB (8-10 mils)	650A 210V	0.25	0.25	.039
103-11 (Vor#11)	XG684/16.6%CAB	725A (8-10 mils)	0.25 222V	0.25	.033
103-12 (Vor#14)	XG684/16.6%CAB	725A (8-10 mils)	0.25 222V	0.25	.029

Table B.6 (continued)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
103-13** (Vor#7)	(4-6 mils)	XG684/16.6%CAB 200V	575A	0.25	0.25 .019
103-14** (Vor#8)	(4-6 mils)	XG684/16.6%CAB 210V	650A	0.25	0.25 .032
103-15** (Vor#12)		XG684/16.6%CAB (4-9 mils)	725A 222V	0.25	0.25 .021
103-16 (Vor#13)	XG684/16.6%CAB	725A (4-6 mils)	0.25 222V	0.25	.043

** cross-sectioned in one area for microscopy

Table B.7

Set 108: 'Medium Grind' XG684 Glass/10 wt% CAB Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
108-1 (Vor#3)	M-XG684/10%CAB (6-8 mils)	900A	0.25	0.50	.000
108-2 (Vor#4)	M-XG684/10%CAB (6-8 mils)	725A	0.25	0.375	.017
108-3 (Vor#6)	M-XG684/10%CAB (6-8 mils)	685A	0.25	0.375	.013
108-4 (Vor#7)	M-XG684/10%CAB (6-8 mils)	685A	0.25	0.375	.021

Table B.8

Set 109: 'Fine Grind' XG684 Glass/10 wt% CAB Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
109-1 (Vor#2)	F-XG684/10%CAB (6.5-7.5 mils)	900A	0.25	0.50	.018
109-2 (Vor#1)	F-XG684/10%CAB (6.5-7.5 mils)	925A	0.25	0.50	.018
109-3 (Vor#8)	F-XG684/10%CAB (5.5-6.5 mils)	850A	0.25	0.50	na
109-4 (Vor#5)	F-XG684/10%CAB (5.5-6.5 mils)	685A	0.25	0.375	.016

Table B.9

Set 110: XG684/5% Sodium Silicate Glass Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
110-1 (Vor#1)	XG684/5%NaSilicate (4.7-5.6 mils)	550A 206V	0.25	0.25	na
110-2** (Vor#3)	XG684/5%NaSilicate (4.8-5.7 mils)	675A 220V	0.25	0.25	.023
110-4 (Vor#4)	XG684/5%NaSilicate (4.6-5.6 mils)	725A 230V	0.25	0.25	na
110-5** (Vor#5)	XG684/5%NaSilicate (5.0-6.2 mils)	725A 230V	0.25 Nickel flash on steel	0.25	.070

** cross-sectioned in one area for microscopy

Table B.10
Set 111: XG684/10% Sodium Silicate Glass Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
111-1** (Vor#2)	XG684/10%NaSilicate (2.9-3.6 mils)	675A 220V		0.25	0.25 .051
111-2** (Vor#6)	XG684/10%NaSilicate (3.1-3.7 mils)	725A 230V		0.25	0.25 na
111-3 (Vor#7)	XG684/10%NaSilicate (6.3-7.3mils)	725A 230V	0.25	0.25	.043
111-4 (Vor#8)	XG684/10%NaSilicate (6.6-7.9mils)	725A 230V	0.25	0.25	.036
111-5** (Vor#9)	XG684/10%NaSilicate (2.9-4.1mils)	725A 230V	Nickel flash on steel	0.25	0.25 .046

** cross-sectioned in one area for microscopy

Table B.11
Set 112: XG684/15% Sodium Silicate/10% Silica Glass Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
112-1** (Vor#10)	XG684/15%NaSil/10% Silica (4.8-5.6 mils)	725A 230V	0.25	0.25	.035
112-2 (Vor#11)	XG684/15%NaSil/10% Silica (4.7-5.6 mils)	725A 230V	0.25	0.25	.035
112-3 (Vor#12)	XG684/15%NaSil/10% Silica (7.9-9.5 mils)	725A 230V	0.25	0.25	.052
112-4 (Vor#13)	XG684/15%NaSil/10% Silica (8.4-9.5mils)	725 230V	0.25	0.25	.033
112-5 (Vor#14)	XG684/15%NaSil/10% Silica (4.9-6.8mils)	725 230V	0.25	0.25 Nickel flash on steel	.030

** cross-sectioned in one area for microscopy

Table B.12
Set 113: XG684 Glass/20% Sodium Silicate/10% Silica/5%Bentonite Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
113-1** (Vor#15)	XG684/20%NaSil/15% Other	725A (3.4-4.6 mils) 230V		0.25	0.25 .041
113-2** (Vor#16)	XG684/15%NaSil/10% Other	725A (3.4-4.6 mils) 230V		0.25	0.25 .046
113-3 (Vor#17)	XG684/15%NaSil/10% Other	725A (4.0-5.1 mils) 230V	0.25	0.25	.030
113-4 (Vor#18)	XG684/15%NaSil/10% Other	725A (4.3-4.7 mils) 230V	0.25	0.25	.035
113-5** (Vor#19)	XG684/15%NaSil/10% Other	725A (4.0-4.8 mils) 230V	0.25	0.25 Nickel flash on steel	0.25 .036

** cross-sectioned in one area for microscopy

Table B.12
Set 114: XG684 Glass/10% CAB 381.01 Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
114-1 (Vor#1)	XG684/10%CAB (3.9-4.8 mils)	550A	0.25	0.25	.023
114-2** (Vor#2)	XG684/10%CAB (3.5-4.1 mils)	600A 215V	0.25	0.25	.028
114-3** (Vor#3)	XG684/10%CAB (4.0-4.6 mils)	600A 215V Nickel flash on steel	0.25	0.25	.030
114-4** (Vor#4)	XG684/10%CAB (4.0-4.5 mils)	600A 215V Nickel plate on steel	0.25	0.25	.029
114-5 (Vor#5)	XG684/10%CAB (7.2-7.8 mils)	600A 215V	0.25	0.25	.040
114-6 (Vor#6)	XG684/10%CAB (7.2-7.8 mils)	600A 215V	0.25	0.25	.045
114-7** (Vor#7)	XG684/10%CAB (3.4-6.3 mils)	600A 215V Nickel flash on steel	0.25	0.25	.038
114-8 (Vor#8)	XG684/10%CAB (6.5-8.6 mils)	600A 215V Nickel plate on steel	0.25	0.25	.033

** cross-sectioned in one area for microscopy

Table B.14
Set 115: Metco 34F Cermet/10% Elvanol 52-22 Coating
(* 4" x 8" and all sample numbers prefixed by 94-J23-B6822-)

ORTECH Sample Number*	Sprayed Coating Material	Lamp Power (A, V)	Substrate Speed (in/sec)	Substrate Thickness (inches)	Observed Warpage (inches)
115-1** (Vor#9)	34F/10% Elvanol (3.0-3.4 mils)	725A 230V	0.25	0.25	.081
115-2** (Vor#10)	34F/10% Elvanol (2.2-2.7 mils)	725A 230V	0.25	0.25	.053
115-3** (Vor#11)	34F/10% Elvanol (3.1-3.7 mils)	725A 230V	0.25 Nickel flash on steel	0.25	.071
115-4** (Vor#12)	34F/10% Elvanol (3.1-3.7 mils)	725A 230V	0.25 Nickel plate on steel	0.25	.064

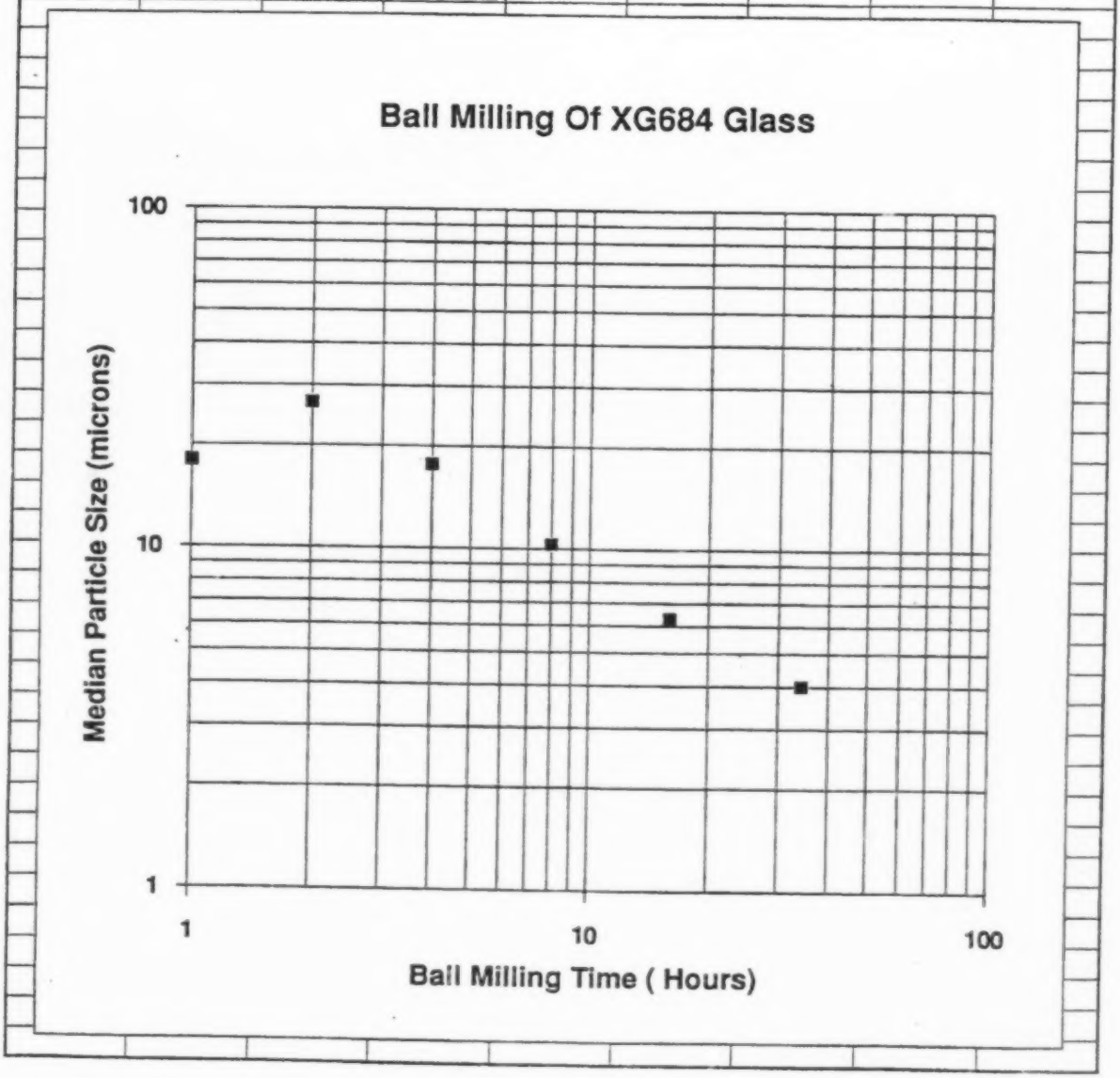
** cross-sectioned in one area for microscopy

14. Appendix C: Ball Milled Glass Particle Size Results

(13 page)

ORTECH--Vortek Ph 2--J23-B004136-0200--B. G. Sellars
Filename: BMILL684.XLS--Print Date: 95/02/08--Page 1 of 1

Ball Milling	Median P	Volume Mean Particle Size (microns)
1	18	23.5
2	26.7	32.1
4	17.7	22.8
8	10.3	13.2
16	6.3	8.5
34.25	4	6.3



ORTECH

Software Version 1.2

Thu, Feb 9, 1995 2:34PM

SAMPLE IDENTIFICATION 95J426996-09 :Run Number: 1

SAMPLE 95J426996-09-XGL684-7
DISPERSED IN ACETONE, I MINUTE SONICATION (80 Watt)
10,000 SWEEPS, 100MM LENS
OPERATOR BRAD SMITH
Sample File Name: TEST4 , Record: 126 Source: Laser Diffraction Analyzer
Measured on: Thu, Feb 9, 1995 2:22PM Last saved on: Thu, Feb 9, 1995 2:33PM

Presentation: 2OAD
Polydisperse model

VOLUME RESULTS

Focus = 100 mm.

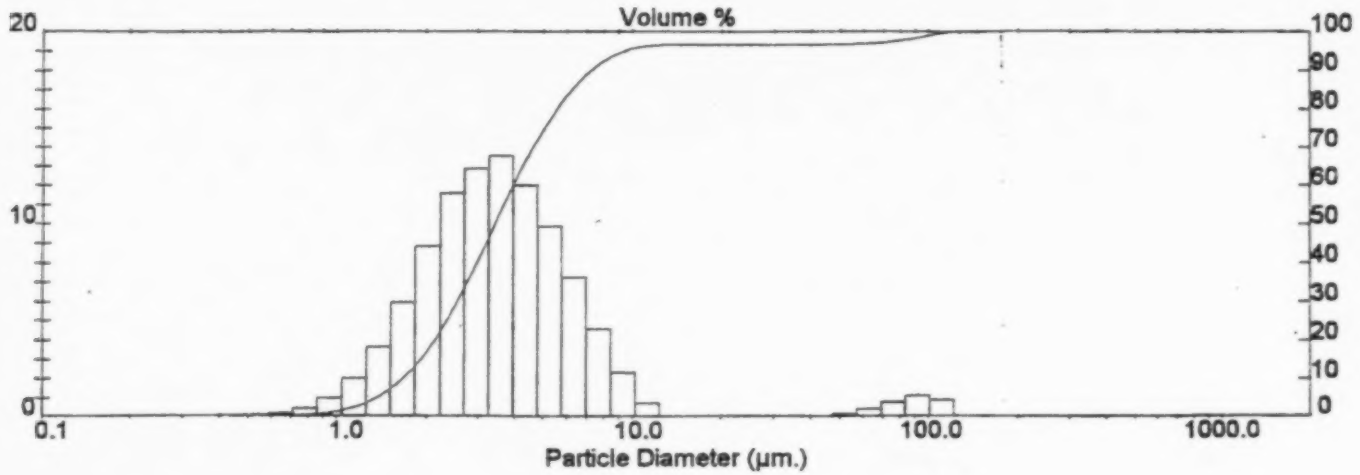
Residual = 0.600 %
MEDIAN = 3.44 µm
MEAN (VOLUME) = 6.62 µm
MODE = 3.53 µm

Concentration = 0.012 %
d (0.1) = 1.68 µm
Span = (d0.9 - d0.1)/d0.5 = 1.62

Obscuration = 32.50 %
d (0.9) = 7.25 µm

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.07	0.59	0.07
0.59	0.17	0.71	0.24
0.71	0.42	0.86	0.66
0.86	0.97	1.04	1.63
1.04	2.01	1.26	3.63
1.26	3.65	1.52	7.28
1.52	5.93	1.84	13.21
1.84	8.80	2.23	22.01
2.23	11.57	2.70	33.58
2.70	12.84	3.27	46.42
3.27	13.50	3.95	59.91
3.95	11.99	4.79	71.91
4.79	9.87	5.79	81.77
5.79	7.23	7.01	89.00
7.01	4.57	8.48	93.57

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	2.33	10.27	95.90
10.27	0.73	12.43	96.62
12.43	0.01	15.05	96.64
15.05	0.00	18.21	96.64
18.21	0.00	22.04	96.64
22.04	0.00	26.68	96.64
26.68	0.00	32.29	96.64
32.29	0.00	39.08	96.64
39.08	0.00	47.30	96.64
47.30	0.18	57.25	96.82
57.25	0.41	69.30	97.23
69.30	0.78	83.87	98.01
83.87	1.12	101.52	99.13
101.52	0.86	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



rn Instruments Inc.
borough, MA

MasterSizer X Ver. 1.2
Serial No. 6286

09 Feb 95 14:3

ORTECH

Software Version 1.2

Mon, Jan 30, 1995 11:12AM

95J42899607XG684B :Run Number 2

AMPLE 95-J42-6996-07-XG684-B 12 hr
ISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
),000 SWEEPS MEASURED
PERATOR BRAD SMITH
mple File Name: TEST4 , Record: 100
asured on: Mon, Jan 30, 1995 11:02AM Last saved on: Mon, Jan 30, 1995 11:04AM

Source: Laser Diffraction Analyzer

sentation: 2OAD
ydisperse model

Volume Result

Concentration = 0.027 %
d (0.1) = 3.67 µm
Span = (d0.9 - d0.1)/d0.5 = 2.03

Focus = 100 mm.

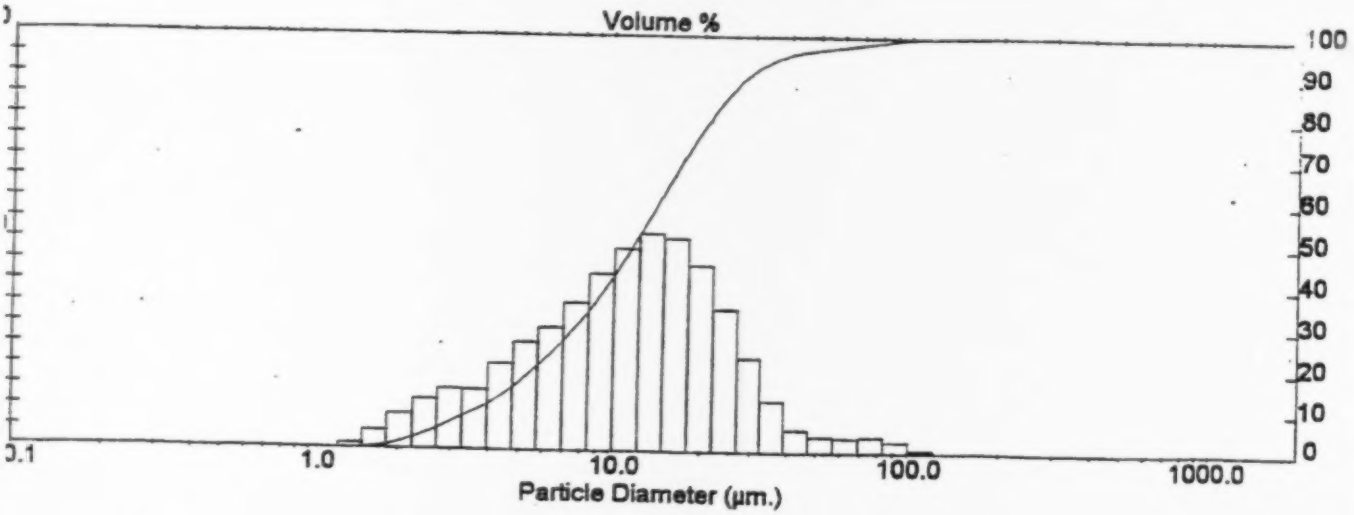
Obscuration = 25.18 %
d (0.9) = 28.04 µm

MODE = 14.69 µm
Density = 1.00 gm. / c.c.

sidual = 0.476 %
DIAN = 11.97 µm
LUME MEAN = 15.21 µm
ter Mean (D[3,2]) = 8.07 µm
cific Surface Area = 0.7433 sq. m. / gm

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.00	1.26	0.00
1.26	0.27	1.52	0.27
1.52	0.90	1.84	1.17
1.84	1.71	2.23	2.88
2.23	2.43	2.70	5.31
2.70	2.95	3.27	8.27
3.27	2.93	3.95	11.20
3.95	4.21	4.79	15.40
4.79	5.23	5.79	20.63
5.79	5.94	7.01	26.58
7.01	7.12	8.48	33.70

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	8.54	10.27	42.24
10.27	9.74	12.43	51.98
12.43	10.47	15.05	62.45
15.05	10.26	18.21	72.71
18.21	8.99	22.04	81.70
22.04	6.90	26.68	88.60
26.68	4.55	32.29	93.15
32.29	2.51	39.08	95.66
39.08	1.15	47.30	96.81
47.30	0.81	57.25	97.63
57.25	0.76	69.30	98.39
69.30	0.81	83.87	99.20
83.87	0.60	101.52	99.80
101.52	0.19	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



nstruments Inc.
ugh, MA

MasterSizer X Ver. 1.2
Serial No. 6286

30 Jan 95 11:12

ORTECH

Software Version 1.2

Mon, Jan 30, 1995 11:06AM

95J42699607XG684A :Run Number 3

SAMPLE 95-J42-6996-07-XG684-A (12)
DISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
0,000 SWEEPS MEASURED
OPERATOR BRAD SMITH
ample File Name: TEST4 , Record: 102
easured on: Mon, Jan 30, 1995 11:05AM Last saved on: Mon, Jan 30, 1995 11:06AM

Source: Laser Diffraction Analyzer

esentation: 2OAD
lydisperse model

sidual = 0.332 %
EDIAN = 10.99 µm
OLUME MEAN = 14.80 µm
uter Mean (D[3,2]) = 7.42 µm
ecific Surface Area = 0.8088 sq. m. / gm

Volume Result

Concentration = 0.040 %
d (0.1) = 3.30 µm
Span = (d0.9 - d0.1)/d0.5 = 2.12

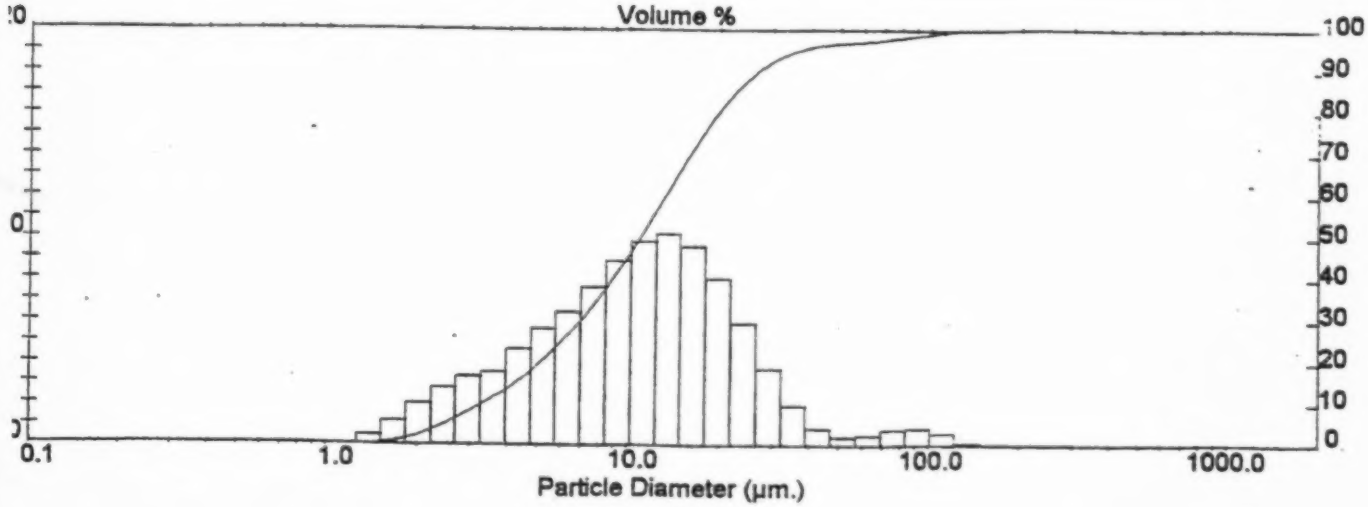
Focus = 100 mm.

Obscuration = 37.53 %
d (0.9) = 26.59 µm

MODE = 13.45 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.03	1.26	0.03
1.26	0.46	1.52	0.50
1.52	1.17	1.84	1.67
1.84	2.03	2.23	3.70
2.23	2.79	2.70	6.49
2.70	3.34	3.27	9.82
3.27	3.54	3.95	13.36
3.95	4.66	4.79	18.02
4.79	5.63	5.79	23.65
5.79	6.46	7.01	30.11
7.01	7.61	8.48	37.71

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	8.88	10.27	46.59
10.27	9.82	12.43	56.41
12.43	10.18	15.05	66.59
15.05	9.57	18.21	76.16
18.21	8.03	22.04	84.19
22.04	5.89	26.68	90.08
26.68	3.71	32.29	93.79
32.29	1.96	39.08	95.75
39.08	0.86	47.30	96.61
47.30	0.45	57.25	97.07
57.25	0.54	69.30	97.61
69.30	0.78	83.87	98.39
83.87	0.86	101.52	99.25
101.52	0.62	122.87	99.86
122.87	0.13	148.72	100.00
148.72	0.00	180.00	100.00



Instruments Inc.
ough. MA

MasterSizer X Ver. 1.2
Serial No. 6286

30 Jan 95 11:0

ORTECH

Software Version 1.2

Tue, Feb 07, 1995 11:18AM

95J42-6996-09-0-300 :Run Number 1

SAMPLE 95J42-6996-09-XGL684-0 Ok.
DISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
10,000 SWEEPS MEASURED
OPERATOR BRAD SMITH

easured on: Tue, Feb 07, 1995 10:51AM

Source: Laser Diffraction Analyzer

esentation: 2OAD
olydisperse model

Volume Result

Focus = 300 mm.

sidual = 0.539 %
EDIAN = 69.97 µm
OLUME MEAN = 83.80 µm
uter Mean (D[3,2]) = 25.42 µm
ecific Surface Area = 0.2361 sq. m. / gm

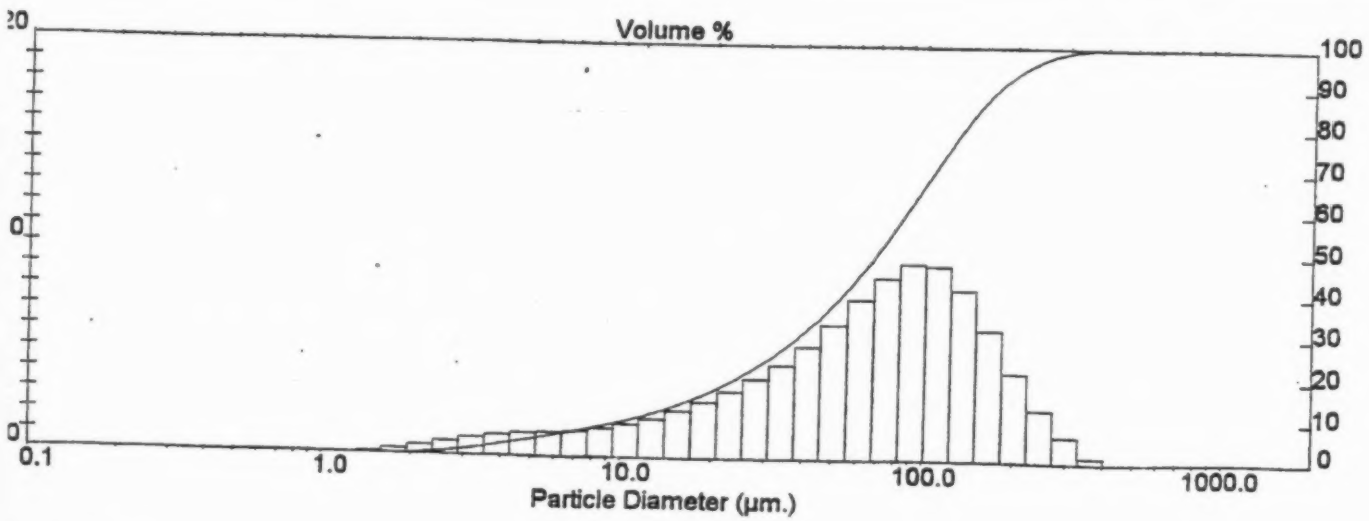
Concentration = 0.080 %
d (0.1) = 11.17 µm
Span = (d0.9 - d0.1)/d0.5 = 2.33

Obscuration = 23.01 %
d (0.9) = 174.41 µm

MODE = 100.15 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.50	0.00	1.32	0.00
1.32	0.11	1.60	0.11
1.60	0.28	1.95	0.39
1.95	0.48	2.38	0.87
2.38	0.70	2.90	1.57
2.90	0.90	3.53	2.47
3.53	1.05	4.30	3.52
4.30	1.16	5.24	4.68
5.24	1.23	6.39	5.91
6.39	1.29	7.78	7.21
7.78	1.44	9.48	8.65
9.48	1.64	11.55	10.29
11.55	1.95	14.08	12.25
14.08	2.33	17.15	14.58
17.15	2.79	20.90	17.37
20.90	3.30	25.46	20.67

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
25.46	3.90	31.01	24.57
31.01	4.61	37.79	29.18
37.79	5.50	46.03	34.67
46.03	6.57	56.09	41.24
56.09	7.75	68.33	48.99
68.33	8.84	83.26	57.83
83.26	9.53	101.44	67.36
101.44	9.43	123.59	76.79
123.59	8.27	150.57	85.07
150.57	6.37	183.44	91.43
183.44	4.31	223.51	95.74
223.51	2.61	272.31	98.35
272.31	1.33	331.77	99.67
331.77	0.32	404.21	100.00
404.21	0.00	492.47	100.00
492.47	0.00	600.00	100.00



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MasterSizer X Ver. 1.2
Serial No. 6286

07 Feb 95 11:1

ORTECH

Software Version 1.2

Tue, Feb 07, 1995 10:04AM

95J42-6996-09-1 :Run Number 1

MPLE 95J42-6996-09-XGL684-1
SPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
000 SWEEPS MEASURED
ERATOR BRAD SMITH
ple File Name: TEST4 , Record: 117
sured on: Tue, Feb 07, 1995 10:00AM Last saved on: Tue, Feb 07, 1995 10:04AM

Source: Laser Diffraction Analyzer

entation: 2OAD
disperse model

Volume Result

dual = 0.561 %
IAN = 18.03 µm
UME MEAN = 23.54 µm
r Mean (D[3,2]) = 10.20 µm
ific Surface Area = 0.5883 sq. m. / gm

Concentration = 0.064 %
d (0.1) = 4.21 µm
Span = (d0.9 - d0.1)/d0.5 = 2.54

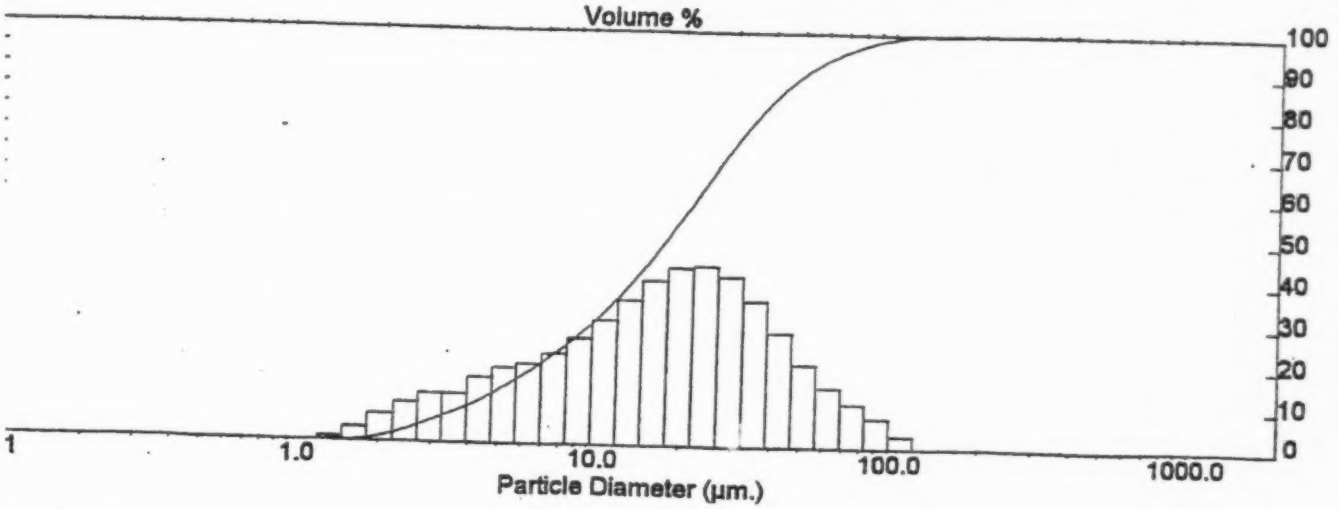
Focus = 100 mm.

Obscuration = 41.79 %
d (0.9) = 50.08 µm

MODE = 22.99 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.00	1.26	0.00
1.26	0.22	1.52	0.22
1.52	0.71	1.84	0.93
1.84	1.36	2.23	2.29
2.23	1.96	2.70	4.24
2.70	2.39	3.27	6.64
3.27	2.40	3.95	9.04
3.95	3.21	4.79	12.25
4.79	3.70	5.79	15.95
5.79	3.92	7.01	19.87
7.01	4.40	8.48	24.28

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	5.14	10.27	29.41
10.27	6.03	12.43	35.44
12.43	7.02	15.05	42.46
15.05	7.97	18.21	50.44
18.21	8.61	22.04	59.05
22.04	8.74	26.68	67.79
26.68	8.22	32.29	76.01
32.29	7.08	39.08	83.10
39.08	5.55	47.30	88.64
47.30	4.06	57.25	92.70
57.25	2.95	69.30	95.65
69.30	2.17	83.87	97.82
83.87	1.50	101.52	99.32
101.52	0.68	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



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MasterSizer X Ver. 1.2
Serial No. 6286

07 Feb 95 10:04

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Software Version 1.2

Tue, Feb 07, 1995 10:08AM

95J42-6996-09-2 :Run Number 1

AMPLE 95J42-6996-09-XGL684-2 2 hr
SPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
,000 SWEEPS MEASURED
ERATOR BRAD SMITH
nple File Name: TEST4 , Record: 118
asured on: Tue, Feb 07, 1995 10:08AM Last saved on: Tue, Feb 07, 1995 10:08AM

Source: Laser Diffraction Analyzer

sentation: 2OAD
disperse model

idual = 0.828 %
DIAN = 26.73 µm
.UME MEAN = 32.06 µm
Mean (D[3,2]) = 14.98 µm
cific Surface Area = 0.4006 sq. m. / gm

Volume Result

Concentration = 0.044 %
d (0.1) = 6.48 µm
Span = (d0.9 - d0.1)/d0.5 = 2.21

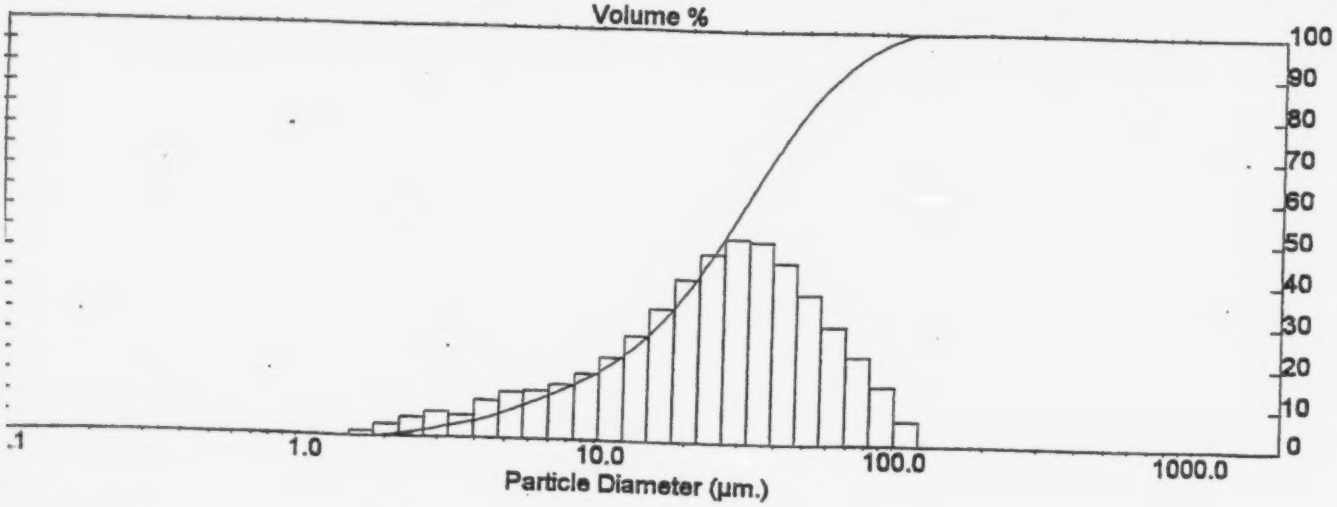
Focus = 100 mm.

Obscuration = 21.34 %
d (0.9) = 65.61 µm

MODE = 31.60 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.00	1.26	0.00
1.26	0.03	1.52	0.03
1.52	0.26	1.84	0.30
1.84	0.63	2.23	0.93
2.23	1.00	2.70	1.93
2.70	1.29	3.27	3.22
3.27	1.15	3.95	4.37
3.95	1.90	4.79	6.27
4.79	2.33	5.79	8.60
5.79	2.40	7.01	11.00
7.01	2.73	8.48	13.72

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	3.31	10.27	17.03
10.27	4.11	12.43	21.14
12.43	5.16	15.05	26.30
15.05	6.50	18.21	32.80
18.21	7.92	22.04	40.73
22.04	9.18	26.68	49.91
26.68	9.92	32.29	59.83
32.29	9.80	39.08	69.63
39.08	8.80	47.30	78.43
47.30	7.30	57.25	85.73
57.25	5.78	69.30	91.51
69.30	4.33	83.87	95.84
83.87	2.89	101.52	98.73
101.52	1.26	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



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MasterSizer X Ver. 1.2
Serial No. 6286

07 Feb 95 10:08

ORTECH

Software Version 1.2

Tue, Feb 07, 1995 10:22AM

95J42-6996-09-3 :Run Number 1

SAMPLE 95J42-6996-09-XGL684-3 4 hr
DISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
10,000 SWEEPS MEASURED
OPERATOR BRAD SMITH
Sample File Name: TEST4 , Record: 119
Measured on: Tue, Feb 07, 1995 10:21AM Last saved on: Tue, Feb 07, 1995 10:21AM

Source: Laser Diffraction Analyzer

Presentation: 2OAD
Polydisperse model

Volume Result

Residual = 0.556 %
MEDIAN = 17.73 µm
VOLUME MEAN = 22.75 µm
Sauter Mean (D[3,2]) = 11.14 µm
Specific Surface Area = 0.5384 sq. m. / gm

Concentration = 0.039 %
d (0.1) = 4.99 µm
Span = (d0.9 - d0.1)/d0.5 = 2.21

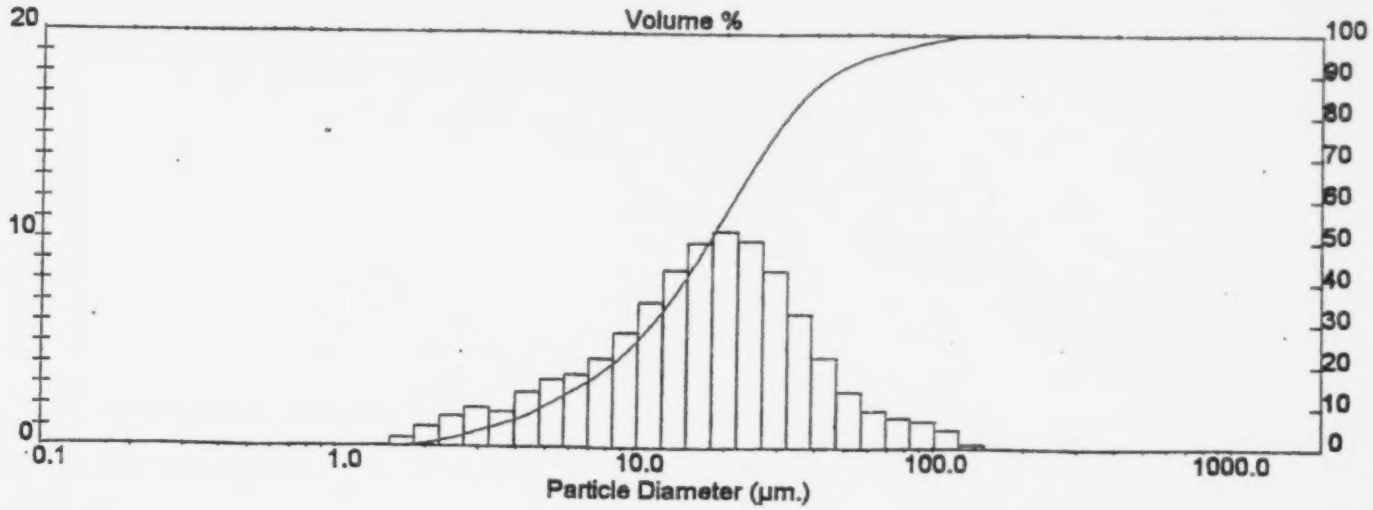
Focus = 100 mm.

Obscuration = 25.48 %
d (0.9) = 44.16 µm

MODE = 20.26 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.00	1.26	0.00
1.26	0.08	1.52	0.08
1.52	0.44	1.84	0.52
1.84	0.99	2.23	1.52
2.23	1.52	2.70	3.04
2.70	1.90	3.27	4.94
3.27	1.74	3.95	6.68
3.95	2.65	4.79	9.32
4.79	3.26	5.79	12.58
5.79	3.53	7.01	16.11
7.01	4.32	8.48	20.43

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	5.55	10.27	25.97
10.27	7.01	12.43	32.98
12.43	8.56	15.05	41.55
15.05	9.89	18.21	51.43
18.21	10.46	22.04	61.90
22.04	10.01	26.68	71.91
26.68	8.57	32.29	80.48
32.29	6.50	39.08	86.98
39.08	4.38	47.30	91.36
47.30	2.75	57.25	94.11
57.25	1.86	69.30	95.97
69.30	1.51	83.87	97.48
83.87	1.33	101.52	98.81
101.52	0.94	122.87	99.75
122.87	0.25	148.72	100.00
148.72	0.00	180.00	100.00



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MasterSizer X Ver. 1.2
Serial No. 6286

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Software Version 1.2

Tue, Feb 07, 1995 10:31AM

95J42-6996-09-4 :Run Number 1

AMPLE 95J42-6996-09-XGL684-4 8hr
ISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
0,000 SWEEPS MEASURED
PERATOR BRAD SMITH
mple File Name: TEST4 , Record: 120
easured on: Tue, Feb 07, 1995 10:30AM Last saved on: Tue, Feb 07, 1995 10:31AM

Source: Laser Diffraction Analyzer

sentation: 2OAD
ydisperse model

Volume Result

idual = 0.423 %
DIAN = 10.25 µm
.UME MEAN = 13.22 µm
ter Mean (D[3,2]) = 7.05 µm
cific Surface Area = 0.8505 sq. m. / gm

Concentration = 0.051 %
d (0.1) = 3.22 µm
Span = (d0.9 - d0.1)/d0.5 = 1.99

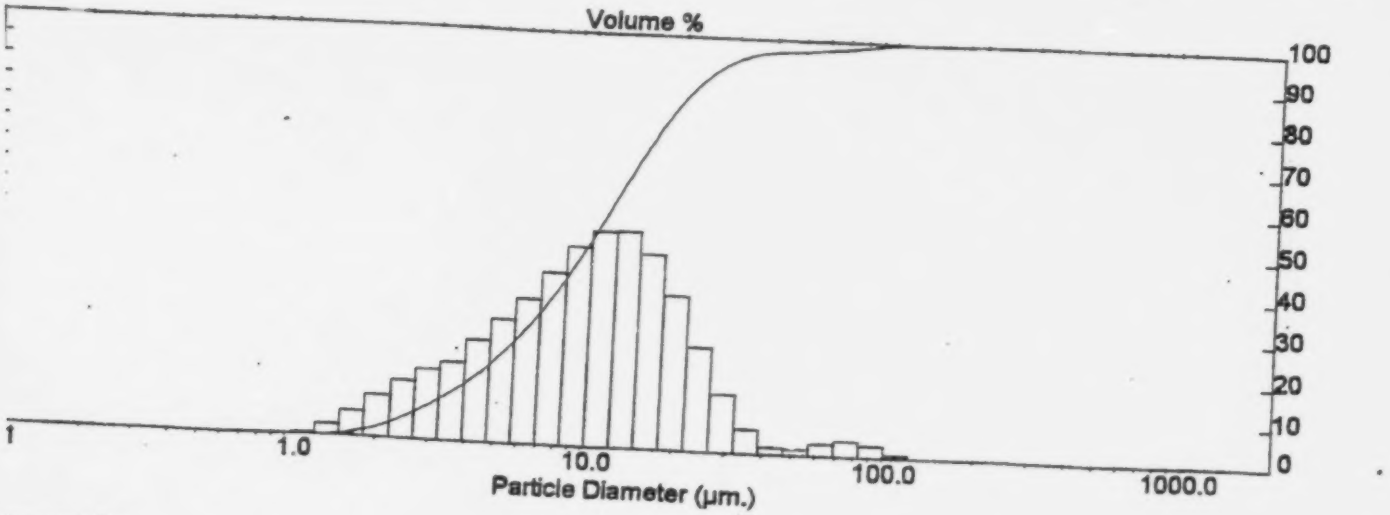
Focus = 100 mm.

Obscuration = 46.81 %
d (0.9) = 23.63 µm

MODE = 12.49 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.11	1.26	0.11
1.26	0.56	1.52	0.67
1.52	1.26	1.84	1.93
1.84	2.09	2.23	4.02
2.23	2.85	2.70	6.87
2.70	3.43	3.27	10.30
3.27	3.81	3.95	14.11
3.95	4.93	4.79	19.05
4.79	6.01	5.79	25.06
5.79	7.06	7.01	32.12
7.01	8.34	8.48	40.46

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	9.64	10.27	50.10
10.27	10.44	12.43	60.53
12.43	10.46	15.05	71.00
15.05	9.41	18.21	80.41
18.21	7.47	22.04	87.87
22.04	5.08	26.68	92.95
26.68	2.86	32.29	95.81
32.29	1.23	39.08	97.04
39.08	0.38	47.30	97.42
47.30	0.34	57.25	97.76
57.25	0.62	69.30	98.37
69.30	0.79	83.87	99.17
83.87	0.61	101.52	99.78
101.52	0.22	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



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MasterSizer X Ver. 1.2

ORTECH

Software Version 1.2

Tue, Feb 07, 1995 10:41AM

95J42-6996-09-5 :Run Number 1

AMPLE 95J42-6996-09-XGL684-5 16th
ISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
0,000 SWEEPS MEASURED
PERATOR BRAD SMITH
mple File Name: TEST4 , Record: 121
easured on: Tue, Feb 07, 1995 10:41AM Last saved on: Tue, Feb 07, 1995 10:41AM

Source: Laser Diffraction Analyzer

sentation: 2OAD
lydisperse model

sidual = 0.337 %
DIAN = 6.26 µm
UME MEAN = 8.48 µm
ter Mean (D[3,2]) = 4.95 µm
cific Surface Area = 1.2118 sq. m. / gm

Volume Result

Concentration = 0.026 %
d (0.1) = 2.51 µm
Span = (d0.9 - d0.1)/d0.5 = 1.86

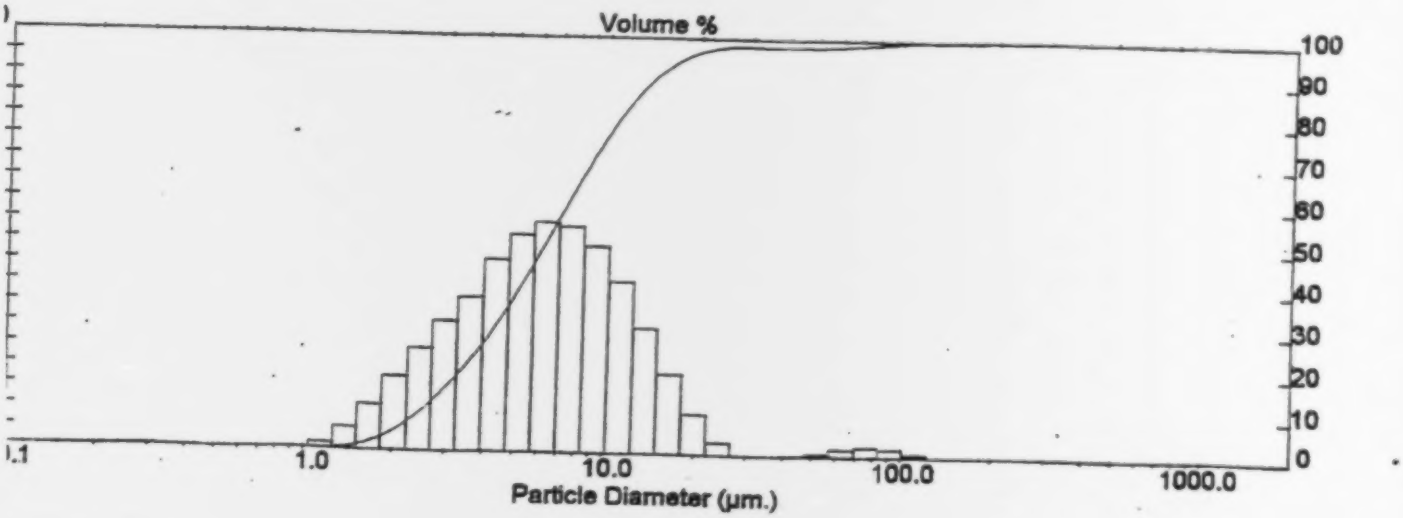
Focus = 100 mm.

Obscuration = 38.12 %
d (0.9) = 14.14 µm

MODE = 6.84 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.31	1.26	0.32
1.26	1.07	1.52	1.39
1.52	2.19	1.84	3.58
1.84	3.55	2.23	7.14
2.23	4.94	2.70	12.08
2.70	6.26	3.27	18.34
3.27	7.43	3.95	25.77
3.95	9.26	4.79	35.03
4.79	10.48	5.79	45.52
5.79	11.08	7.01	56.60
7.01	10.88	8.48	67.48

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	9.94	10.27	77.43
10.27	8.25	12.43	85.68
12.43	6.06	15.05	91.73
15.05	3.83	18.21	95.56
18.21	1.96	22.04	97.53
22.04	0.69	26.68	98.21
26.68	0.03	32.29	98.24
32.29	0.00	39.08	98.24
39.08	0.00	47.30	98.24
47.30	0.17	57.25	98.41
57.25	0.41	69.30	98.82
69.30	0.53	83.87	99.35
83.87	0.46	101.52	99.80
101.52	0.19	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



ORTECH

Software Version 1.2

Tue, Feb 07, 1995 1:44PM

95J42-6996-6 :Run Number 1

SAMPLE 95J42-6996-6 34.1/4-hr.
DISPERSED iN ACETONE, 1 MINUTE SONICATION (80 Watt)
10,000 SWEEPS MEASURED
OPERATOR BRAD SMITH
ample File Name: TEST4 , Record: 125
leasured on: Tue, Feb 07, 1995 1:40PM Last saved on: Tue, Feb 07, 1995 1:44PM

Source: Laser Diffraction Analyzer

resentation: 2OAD
olydisperse model

Volume Result

esidual = 0.450 %
EDIAN = 4.01 µm
OLUME MEAN = 6.31 µm
auter Mean (D[3,2]) = 3.51 µm
pecific Surface Area = 1.7094 sq. m. / gm

Concentration = 0.011 %
d (0.1) = 1.98 µm
Span = (d0.9 - d0.1)/d0.5 = 1.63

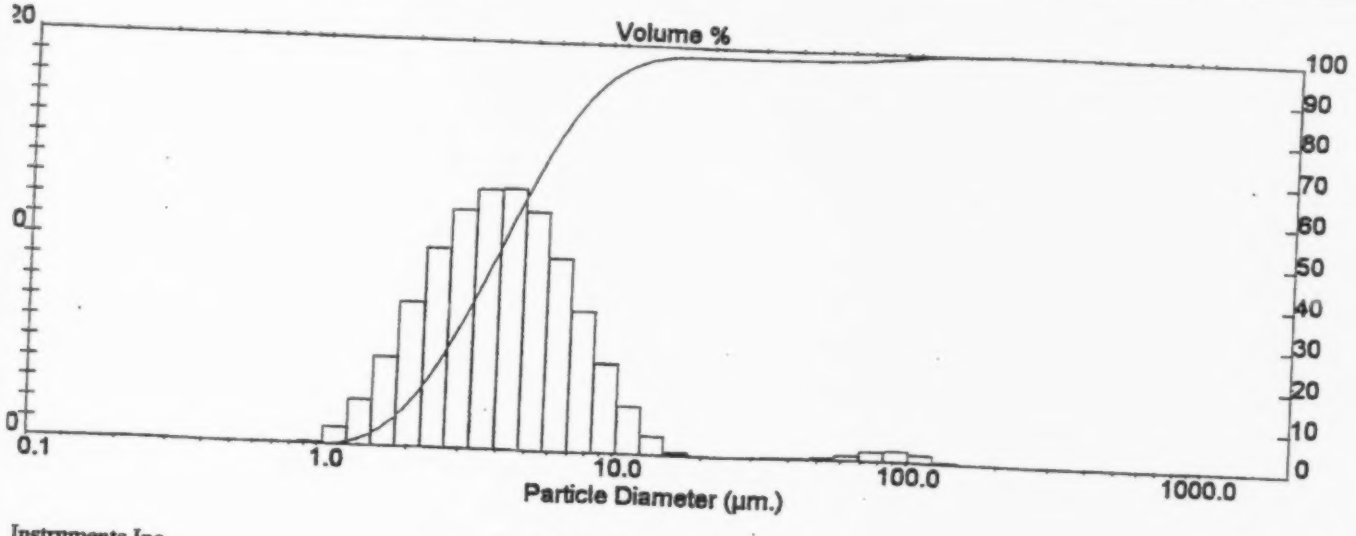
Focus = 100 mm.

Obscuration = 25.53 %
d (0.9) = 8.53 µm

MODE = 3.76 µm
Density = 1.00 gm. / c.c.

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.13	1.04	0.14
1.04	0.88	1.26	1.01
1.26	2.28	1.52	3.29
1.52	4.41	1.84	7.70
1.84	7.11	2.23	14.81
2.23	9.80	2.70	24.61
2.70	11.67	3.27	36.28
3.27	12.71	3.95	48.99
3.95	12.78	4.79	61.77
4.79	11.69	5.79	73.46
5.79	9.46	7.01	82.92
7.01	8.92	8.48	89.84

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	4.41	10.27	94.24
10.27	2.34	12.43	96.59
12.43	0.96	15.05	97.55
15.05	0.22	18.21	97.76
18.21	0.00	22.04	97.77
22.04	0.00	26.68	97.77
26.68	0.03	32.29	97.80
32.29	0.07	39.08	97.86
39.08	0.08	47.30	97.94
47.30	0.15	57.25	98.09
57.25	0.31	69.30	98.41
69.30	0.49	83.87	98.90
83.87	0.57	101.52	99.47
101.52	0.43	122.87	99.90
122.87	0.10	148.72	100.00
148.72	0.00	180.00	100.00



Instruments Inc.
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MasterSizer X Ver. 1.2
Serial No. 6286

07 Feb 95 13:44

ORTECH

Software Version 1.2

Wed, Feb 15, 1995 4:41PM

SAMPLE IDENTIFICATION 94J42699610XGL6841 :Run Number 1

ORTECH #94J42 6996-10 XGL684-1 "MID-GRIND" 12hr 108 SERIES
DISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
10,000 SWEEPS
OPERATOR BRAD SMITH
Sample File Name: TEST4 , Record: 130
Measured on: Wed, Feb 15, 1995 4:34PM Last saved on: Wed, Feb 15, 1995 4:34PM

Source: Laser Diffraction Analyzer

Presentation: 2OAD
Polydisperse model

Residual = 0.357 %
MEDIAN = 7.60 µm
MEAN (VOLUME) = 10.52 µm
MODE = 8.50 µm

VOLUME RESULTS

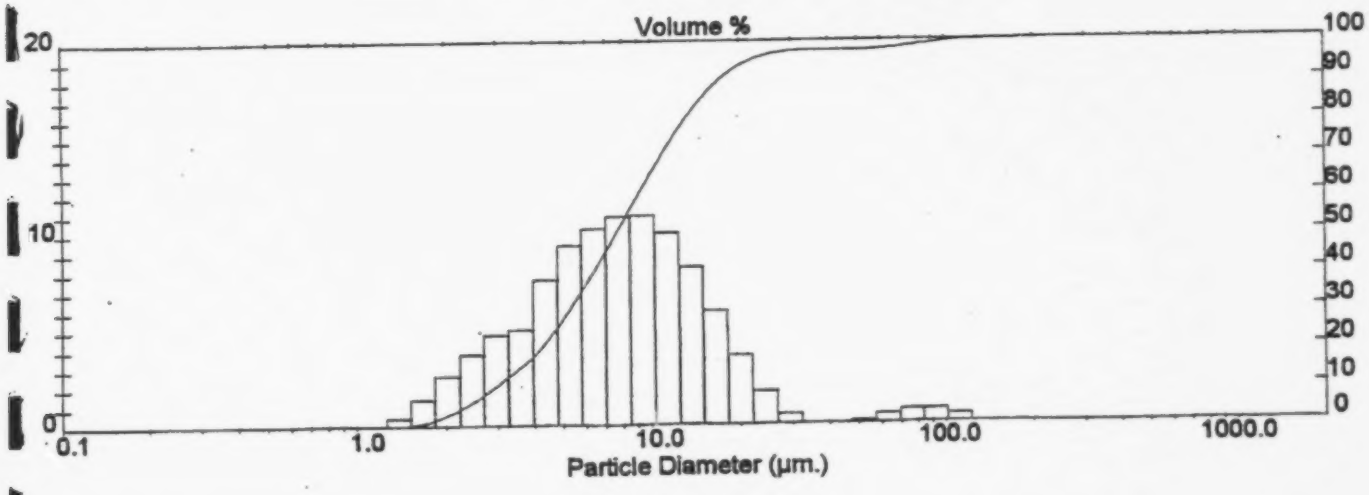
Concentration = 0.011 %
d (0.1) = 2.90 µm
Span = (d0.9 - d0.1)/d0.5 = 1.89

Focus = 100 mm.

Obscuration = 14.97 %
d (0.9) = 17.24 µm

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.00	0.48	0.00
0.48	0.00	0.59	0.00
0.59	0.00	0.71	0.00
0.71	0.00	0.86	0.00
0.86	0.00	1.04	0.00
1.04	0.00	1.26	0.00
1.26	0.48	1.52	0.48
1.52	1.44	1.84	1.92
1.84	2.65	2.23	4.57
2.23	3.76	2.70	8.32
2.70	4.76	3.27	13.08
3.27	5.07	3.95	18.15
3.95	7.61	4.79	25.75
4.79	9.38	5.79	35.14
5.79	10.28	7.01	45.42
7.01	10.87	8.48	56.28

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	10.94	10.27	67.22
10.27	10.03	12.43	77.25
12.43	8.25	15.05	85.50
15.05	5.97	18.21	91.47
18.21	3.67	22.04	95.14
22.04	1.77	26.68	96.91
26.68	0.53	32.29	97.44
32.29	0.01	39.08	97.45
39.08	0.00	47.30	97.45
47.30	0.17	57.25	97.62
57.25	0.50	69.30	98.12
69.30	0.73	83.87	98.84
83.87	0.72	101.52	99.56
101.52	0.44	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



Instruments Inc.
Malvern, MA

MasterSizer X Ver. 1.2
Serial No. 6286

15 Feb 95 16:
BSmith

ORTECH

Software Version 1.2

Wed, Feb 15, 1995 4:49PM

SAMPLE IDENTIFICATION 94J4269969XGL6847 :Run Number 4

ORTECH #94J42 6998-9 XGL684-7 "FINEGRIND" 24-36h.

109 SERIES

DISPERSED IN ACETONE, 1 MINUTE SONICATION (80 Watt)
10,000 SWEEPS
OPERATOR BRAD SMITH
Sample File Name: TEST4 , Record: 131
Measured on: Wed, Feb 15, 1995 4:25PM Last saved on: Wed, Feb 15, 1995 4:49PM

Source: Laser Diffraction Analyzer

Presentation: 2OAD
Polydisperse model

VOLUME RESULTS

Residual = 0.210 %
MEDIAN = 3.45 µm
MEAN (VOLUME) = 5.10 µm
MODE = 3.47 µm

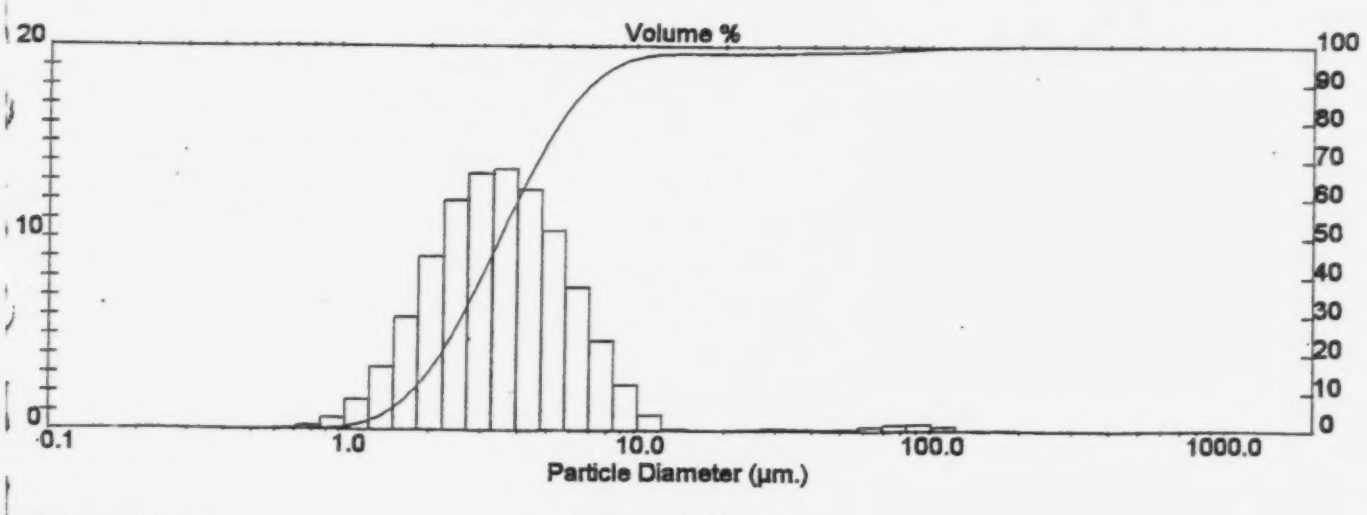
Concentration = 0.009 %
d (0.1) = 1.75 µm
Span = (d0.9 - d0.1)/d0.5 = 1.52

Focus = 100 mm.

Obscuration = 24.87 %
d (0.9) = 6.99 µm

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
0.20	0.02	0.48	0.02
0.48	0.04	0.59	0.06
0.59	0.08	0.71	0.14
0.71	0.22	0.86	0.36
0.86	0.65	1.04	1.00
1.04	1.60	1.26	2.60
1.26	3.31	1.52	5.91
1.52	5.86	1.84	11.77
1.84	9.03	2.23	20.81
2.23	11.96	2.70	32.77
2.70	13.35	3.27	46.12
3.27	13.57	3.95	59.69
3.95	12.52	4.79	72.21
4.79	10.40	5.79	82.61
5.79	7.47	7.01	90.08
7.01	4.71	8.48	94.79

Size (Lo) µm	Result In %	Size (Hi) µm	Result Below %
8.48	2.42	10.27	97.21
10.27	0.87	12.43	98.09
12.43	0.10	15.05	98.19
15.05	0.00	18.21	98.19
18.21	0.00	22.04	98.19
22.04	0.06	26.68	98.25
26.68	0.13	32.29	98.38
32.29	0.12	39.08	98.50
39.08	0.09	47.30	98.59
47.30	0.13	57.25	98.72
57.25	0.25	69.30	98.97
69.30	0.37	83.87	99.34
83.87	0.40	101.52	99.74
101.52	0.26	122.87	100.00
122.87	0.00	148.72	100.00
148.72	0.00	180.00	100.00



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MasterSizer X Ver. 1.2
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15. Appendix D: Vortek Lamp Sintering Trial Results

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ORTECH Samples for DREP Phase II

Experiments run Sept. 26 to Oct 2,1994 (Cermet Melting)

Runs	Sample ID #	Total Film Thickness (mils)	Base Coat Film Thickness (mils)	Translation Velocity	Current	Comments
1	B6822P87-1	9.0-14.0	6.0-8.0	1"/sec	750A	Sample 1cm below focus. After scanning it sample surface appears beaded. In certain spots coating lifted off. Requires more power. Sample warps.
2	B6822P87-2	8.0-11.0	6.0-8.0	1"/sec	800A	Air sweep used. Result: Sample surface appears beaded. Bigger bead when rubbed with a finger rubs loose. Probably needs to be slowed down. Sample warps.
3	B6822P87-3	7.0-11.0	6.0-8.0	0.55"/sec	500A	Air sweep used. Result: Surface still appears in smaller beaded form. Sample warps.
4	B6822P87-4	7.0-11.0	5.0-8.0	0.55"/sec	600A	Air sweep used. Result: Surface appears rough like 180 grit sand paper. It seems like glass has melted into substrate and Cermet appears in grit form which requires more power to melt into substrate.
5	B6822P87-5	8.0-10.0	5.0-7.0	0.55"/sec	700A	Air sweep used. Result: Surface appeared oxidized (i.e. black surface). Patches of silvery appearance. Requires lab analysis. Sample warped.
6	B6822P87-6	7.0-10.0	5.0-7.0	0.55"/sec	650A	Result: Middle of sample looks black with shinny patches. Surface appears like sand paper grit. Sample warped.
7	B6822P87-7	8.0-11.0	5.0-8.0	0.5"/sec	625A	Air sweep used.

Seven samples out of 13 were tested. It showed signs that this type of coating i.e. glass and cermet is possible to melt into substrate. Samples 5 -7 may require lab analysis to determine how the surface looks. Warping seemed to be a problem on the thin samples.

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ORTECH Samples for DREP Phase II

(determining the effect on warpage) Experiments run Sept 26 to Oct 2,1994

Runs	Sample ID #	Metal Thickness (inches)	Coating Thickness (mils)	Translation Velocity	Current	Comments
1	B6822P91-21	1/16"	5.0-10.0	0.55"/sec	375A	Samples set 1 cm below focus. Air sweep was used to blow away soot when the sample was processed. Result: After processing the surface looks blue in colour and lifted off. This indicates that it requires more power. Sample did not warp.
2	B6822P91-23	1/16"	8.0-15.0	0.55"/sec	400A	Air sweep was used to blow away soot when the sample was processed. Result: Same as above. requires more power. Sample didn't warp.
3	B6822P91-22	1/16"	6.0-11.0	0.5"/sec	425A	Result: Surface appeared black in colour and looked like sandpaper grits. These grits became loose. requires more power. Sample warped slightly. Small volume of O_2 flow on the surface of sample.
4	B6822P91-24	1/16"	8.0-15.0	0.5"/sec	450A	Result: Surface appears black, beaded and scaly. Because the coating was thicker it requires more power. Sample slightly warped. Small volume of O_2 flow on the surface of sample.
5	B6822P91-18	1/4"	8.0-15.0	1/4"/sec or 0.25"/sec	475A	Samples set 0.84cm below focus. Result: Surface appeared black, beaded and upon cooling these beads popped off. Requires more power. No warping. Sample stayed quite flat. No O_2 flow used.

(determining the effect on warpage) Experiments run Sept 26 to Oct 2,1994

Runs	Sample ID #	Metal Thickness (inches)	Coating Thickness (mils)	Translation Velocity	Current	Comments
6	B6822P91-19	1/4"	5.0-10.0	1/4"/sec	525A	Samples set 0.84cm below focus. Air sweep used to blow away soot when samples were processed. Result: Good. Very uniform melting of coating into the substrate. Surface looks glassy but scaly. Sample slightly warped. No O_2 flow used.
7	B6822P91-20	1/4"	6.0-10.0	1/2"/sec	675A	Result: Surface black and beaded form. These beads tend to pop off as surface cools down. Requires more power. Hardly any warping. Sample stayed very flat. No O_2 flow used.
8	B6822P91-17	1/4"	8.0-15.0	1/2"/sec	715A	Result: Surface looks black with big beads of glass stuck on it. Sample didn't warp, stayed quite flat. No O_2.
9	B6822P91-13	3/8"	5.0-9.0	1/4"/sec	600A	Samples set 0.5cm below focus Result: Surface looks black, rough and beaded. Upon cooling these beads of glass popped off. May require more power to melt these beads of glass into substrate. No warping - sample stayed very flat.
10	B6822P91-14	3/8"	5.0-10.0	1/4"/sec	650A	Samples set 0.5cm below focus. Air sweep used to blow away soot. Result: Same as above sample.
11	B6822P91-15	3/8"	4.0-9.0	1/4"/sec	700A	Samples set 0.5cm below. Air sweep. Result: Coating did fuse into substrate but surface does not look smooth. Instead it looks black rough and you can see beads of glass. Sample stayed quite flat. Hardly any warping.

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(determining the effect on warpage) Experiments run Sept 26 to Oct 2,1994

Runs	Sample ID #	Metal Thickness (inches)	Coating Thickness (mils)	Translation Velocity	Current	Comments
12	B6822P91-16	3/8"	4.0-10.0	1/4"/sec	750A	Samples set 0.5cm below Result: Same as above. Somehow the data wasn't recorded. Approximate substrate temperature 500°C.
13	B6822P91-9	1/2"	5.0-8.0	1/4"/sec	900A	Sample was set 0.5cm below focus. Result: Coating did fuse into substrate. The surface looked black, rough and one could see beads of glass upon cooling. These beads of glass popped off. Sample stayed very flat. Hardly any warping. At the edge of the sample's surface, one could see melted substrate. This indicates that there was enough power to melt the coating.
14	B6822P91-10	1/2"	5.0-10.-	1/4"/sec	900A	Sample was set 1cm below focus. Result: Same as in run 13.

Notes:

Set Up

Close coupled gold ellipse was used for all tests. Sample scanned perpendicular to arc. Target irradiance given in accompanying figure 1. Notes indicate sample positon with respect to focus of reflector.

1/16" Samples:

Only 4 sets of samples were available. Didn't manage to get a good coating fusion into substrate. The tests did prove that 1/16" substrate thickness warps.

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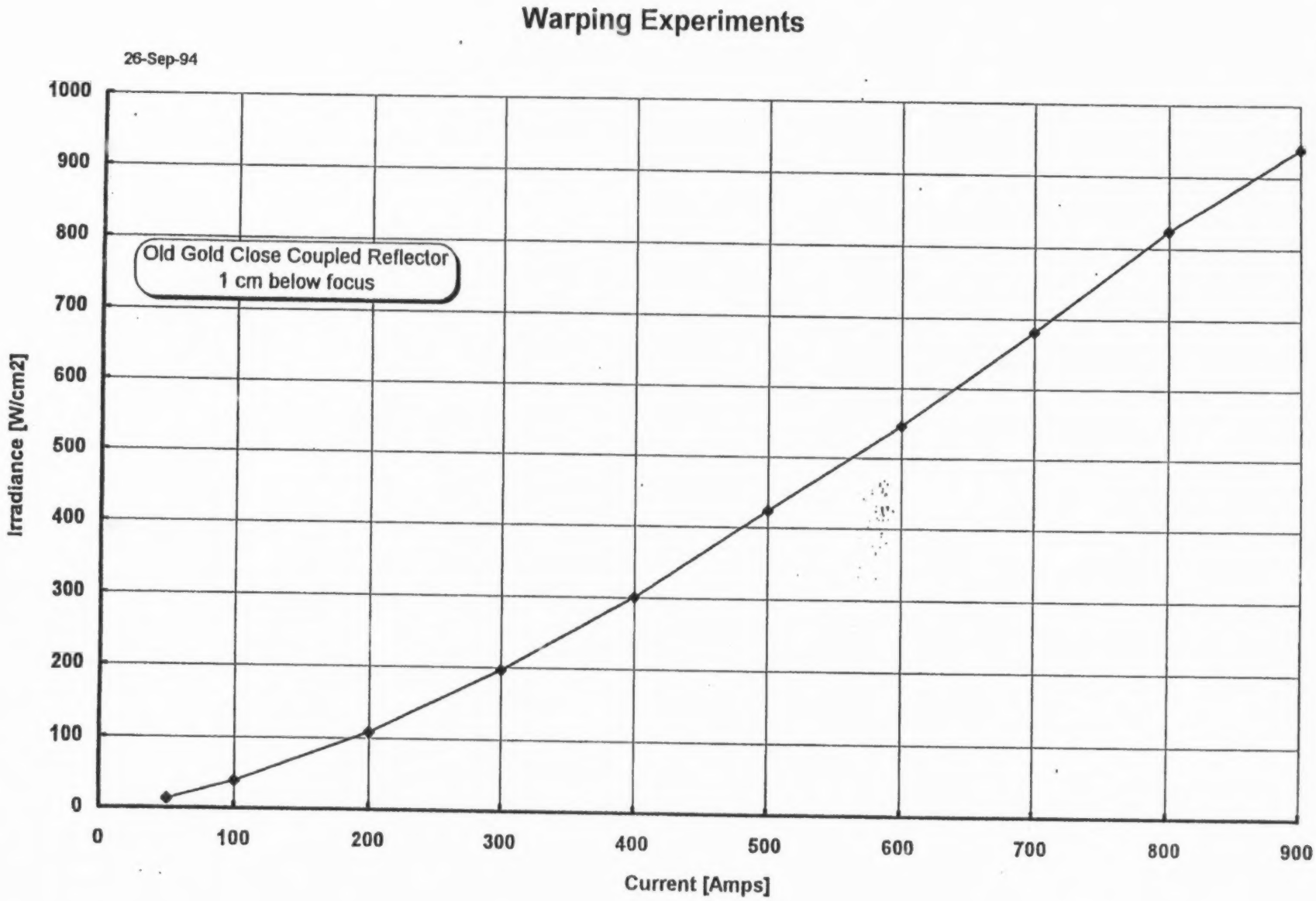

Fig. 1

1/4" Samples:

1/4" substrate thickness showed less warping effect. Most of the sample stayed flat. Also, coating in one sample looked very good.

3/8" Samples

4 Runs conducted on 4 pieces at different power levels. All the samples processed stayed very flat. No warping at all. The only problem was the coating. It melted into substrate but the surface looked beaded and rough. Increasing the power seemed to help but it didn't quite smoothen the surface.

1/2" Samples

2 Sets of samples done out of 4. The first sample was set 0.5cm below focus and the second was set 1cm below focus. The result for the two samples was the same. Warping didn't seem to be a problem. Both samples stayed quite flat. The problem on these two samples was the appearance of the surface after the coating melted into the substrate. The surface appeared black, rough and beads of the glass stuck and upon cooling some of these beads of glass popped off.

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ORTECH DREP Samples Phase II

Test Parameters:

- Rhodium plated reflector used
- Close couple ellipse reflector
- All samples scanned perpendicular to the arc
- All samples 2cm below the mouth of the reflector (i.e. 1cm below focus)
- Air sweep used
- All samples rested on six of 1032 studs
- On all samples coating is on 1/4" thick steel

Run	Panel Identification	Coating	Binder (mils)	Dry Film Thickness	Translation Velocity	Current	Comments
1	94-J23-6822-94-1	XG 684	16.6% CAB	4 - 8	1/4"/sec 0.25"/sec	525A	↓ Coating fused into substrate. Some beads of glass on surface. Require more power.
2	94-J23-6822-94-2	XG 684	16.6% CAB	4 - 7	1/4"/sec 0.25"/sec	550A	↓ Air sweep reduced to 1/2. Coating fused into substrate. Good result. No warping.
3	94-J23-6822-98-1	XG 684	10% CAB	8 - 10	1/4"/sec 0.25"/sec	550A	↓ Air sweep used. Coating melted. Surface appeared rough, beaded and as it cooled the coating popped off. Assume, require more power.
4	94-J23-6822-98-2	XG 684	10% CAB	8 - 10	1/4"/sec 0.25"/sec	600A	↓ Reduced air flow (1/4 flow). In certain spots coating fused into substrate but most of the coating popped off as it cooled.

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Run	Panel Identification	Coating	Binder (mils)	Dry Film Thickness	Translation Velocity	Current	Comments
5	94-J23-6822-98-3	XG 684	10% CAB	8 - 10	1/4"/sec 0.25"/sec	650A	↓ No air sweep used. Current increased, similar result as in run #3 + 4. Wherever the coating fused, surface looks rough and beaded. Upon cooling most of the coating popped off.
6	94-J23-6822-96-1	METCO 34F	16.6% Elvanol 52-22	7 - 10	1/4"/sec 0.25"/sec	725A	↓ Air sweep used. Centre portion a bit shiny and silvery in appearance. Around the edge it is black and a bit rough. Definitely the coating has melted into the substrate.
7	94-J23-6822-96-2	METCO 34F	16.6% Elvanol 52-22	6 - 9	1/4"/sec 0.25"/sec	850A	↓ Air sweep used. Did a run at extreme current. Most of the surface looked quite black. Certain spots look silvery and shiny only.
8	94-J23-6822-96-3	METCO 34F	16.6% Elvanol 52-22	6 - 9	1/4"/sec 0.25"/sec	760A	↓ Air sweep used. Coating did melt into substrate. Surface looks silvery and shiny where as most of the other spot it appears black.
9	94-J23-6822-94-3	XG 684	16.6% CAB	4 - 6	1/4"/sec 0.25"/sec	575A	↓ Air sweep used. Thermocouple used at the back surface of sample to monitor temperature. Current slightly up. Excellent result. Surface appears smooth and shiny.
10	94-J23-6822-98-4	XG 683	10% CAB	7 - 9	1/4"/sec 0.25"/sec	575A	↓ Air sweep used. Thermocouple mounted on back surface. Same current used as in Run #9. Coating popped off as the surface cooled. No data recorded as thermocouple broke.

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Run	Panel Identification	Coating	Binder (mils)	Dry Film Thickness	Translation Velocity	Current	Comments
11	94-J23-6822-94-4	XG 684	16.6% CAB	3 - 7	1/4"/sec 0.25"/sec	575A	↓ Air sweep used. Repeat of Run #9. Good result. Back surface temperature measured using thermocouple. Data recorded on file: Ortec 16% CSV. Surface appears smooth and shiny.
12	94-J23-6822-96-4	METCO 34F	16.6% Elvanol 52-22	6 - 9	1/4"/sec 0.25"/sec	750A	↓ Air sweep used. Temperature measurement taken off the back surface of this sample. Recorded on file: Ortec 34F-CSV. On melted surface I could see silvery and shiny spots but mostly the surface looked rough and black.

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ORTECH DREP Samples Phase II

Objective: To determine the effect of binder content and dry film thickness on 1/4" thick panels.

Test Parameters:

- Rhodium plated reflector used
- Close couple ellipse reflector
- All samples scanned perpendicular to the arc
- All samples 2cm below the mouth of the reflector (i.e. 1cm below focus)
- Air sweep used
- All samples rested on #1032 studs
- On all samples coating is on 1/4" thick steel

Run	Panel Identification	Coating	Binder (mils)	Dry Film Thickness (mils)	Translation Velocity	Operating Current	Comments
1	95-J23-6822-103-1 Paste A	XG 684	10% CAB	8 - 10	1/4"/sec 0.25"/sec	575A 200V Power = 115kW	All tests performed with above test parameters. ↓ Air sweep used. Exposed surface appeared beaded and black. Require more power.
2	95-J23-6822-103-2 Paste A	XG 684	10% CAB	8 - 10	1/4"/sec 0.25"/sec	650A 210V Power = 136.5kW	All tests performed with above test parameters. ↓ Air sweep used. Higher power. Exposed surface appeared beaded and black. Coating did fuse into substrate.
3	95-J23-6822-103-5 Paste A	XG 684	10% CAB	4 - 6	1/4"/sec 0.25"/sec	575A 200V Power = 115kW	Repeat of Run 1 on a panel with thin dry film thickness. When compared with Run 1 sample, the exposed surface looks black and beaded. Beads appear to be much smaller in size.
4	95-J23-6822-103-6 Paste A	XG 684	10% CAB	4 - 6	1/4"/sec 0.25"/sec	650A 210V Power = 136.5kW	Repeat of Run 2 on a panel with thin dry film thickness. When compared to Run 2 sample exposed surface looks black but much smoother.

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Run	Panel Identification	Coating	Binder (mils)	Dry Film Thickness (mils)	Translation Velocity	Current	Comments
5	95-J23-6822-103-9 Paste B	XG 684	16.6% CAB	8 - 10	1/4"/sec 0.25"/sec	575 A 200V Power = 115kW	Repeat of Run 1 on a panel with higher binder %. When compared with Run 1, the exposed surface looks blacker but quite beaded like in Run 3.
6	95-J23-6822-103-10 Paste B	XG684	16.6% CAB	8 - 10	1/4"/sec 0.25"/sec	650A 210V Power = 136.5kW	Repeat of Run 2 on a panel with higher binder %. When compared with Run 2 the exposed surface looks dark black and beaded like Run 4 sample.
7	95-J23-6822-103-13 Paste B	XG684	16.6% CAB	4 - 6	1/4"/sec 0.25"/sec	575A 200V Power = 115kW	All tests performed with the above test parameters. ↓ Air sweep used. When compared with Run 1 sample, the binder % is high and was thin dry film thickness. Result: Exposed surface looks black but much smoother than Runs 1,3 and 5.
8	95-J23-6822-301-14 Paste B	XG684	16.6% CAB	4 - 6	1/4"/sec 0.25"/sec	650A 210V Power = 136.5kW	All tests performed with above test parameters. Air sweep used. When compared with Run 2 sample this panel's binder % is high and it has thin dry film thickness. Result: Exposed surface appears black and smoother when compared to Runs 2, 4 and 6.
9	95-J23-6822-103-3 Paste A	XG 684	10% CAB	8 - 10	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 1 with higher power. Result: Coating did fuse into substrate. Surface appeared beaded and black and upon cooling some of this coating popped off.
10	95-J23-6822-103-7 Paste A	XG 684	10% CAB	4 - 6	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 3 sample with higher power. Result: Coating did fuse into substrate. When compared with Run 9 sample, the surface looks black but scaly and not beaded. Coating did not pop off.

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Run	Panel Identification	Coating	Binder (mils)	Dry Film Thickness (mils)	Translation Velocity	Current	Comments
11	95-J23-6822-103-11 Paste B	XG 684	16.6% CAB	8 - 10	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 5 sample with higher power. result: When compared to Runs 9 & 10 samples, the exposed surface looks black & beaded. Quite like Run 9 sample.
12	95-J23-6822-103-15 Paste B	XG684	16.6% CAB	4 - 9	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 7 sample with higher power. Result: When compared to Runs 9, 10, & 11 this sample looks black but much smoother, i.e. less beaded and scaly. Coating fused into substrate without popping off when cooled.
13	95-J23-6822-103-16 Paste B	XG684	16.6% CAB	4 - 6	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 12 with no air sweep. Result: Exposed surface looks black and smooth. In the middle of this sample the coating lifted off.
14	95-J23-6822-103-12 Paste B	XG684	16.6% CAB	8 - 10	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 11 with no air sweep. Result: During run a lot of soot, which deposited on window and destroyed it. Exposed surface appeared black and beaded. The whole piece of coating lifted off from the middle.
15	95-J23-6822-103-8 Paste A	XG684	10% CAB	4 - 6	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 10 with very low air sweep. Result: Uniform coating fusion into substrate. Surface looks black a bit scaly and beaded.
16	95-J23-6822-103-4 Paste A	XG684	10% CAB	8 - 10	1/4"/sec 0.25"/sec	725A 222V Power = 161kW	Repeat of Run 9 with very low air sweep. Result: Coating fused into substrate but some of it popped off when cooled. The surface looked black and beaded.

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ORTECH DREP Samples Phase II

Objective: To determine the effects of sodium silicate binder on these panels.

Test Parameters:

- Rhodium plated close couple ellipse reflector
- All samples scanned perpendicular to the arc
- All samples 2cm below the mouth of the reflector (i.e. 1cm below focus)
- All samples rested on #1032 studs.
- Samples translated at velocity of 1/4"/sec. (0.25"/sec.)
- Air sweep used on all the samples.

Run	Panel Identification	Coating/Binder Content	Substrate Type	Dry Film Thickness	Operating Current	Comments
1	95-J23-6822-110-1	94-J42-6996-15 5% GD Silicate/XGL684	Grit Blasted Steel	4.7 - 5.6	550A 206V Power = 113.3kW	Tests were performed using above parameters. Run 1 is to establish the right power level Result: Coating did not melt into substrate. Requires more power.
2	95-J23-6822-111-1	94-J42-6996-15 5% GD Silicate/XGL684-2	Grit Blasted Steel	2.9 - 3.6	675A 220V Power = 148.5kW	All tests performed using above test parameters. Run is to establish the right power level. Result: Middle portion of sample coating melted into the substrate. Around the edges the coating did not melt into substrate. May require more power.

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Run	Panel Identification	Coating/Binder Content	Substrate Type	Dry Film Thickness	Operating Current	Comments
3	95-J23-6822-110-2	5% GD Silicate/XGL6 84-1	Grit Blasted Steel	4.8 - 5.7	675A 220V Power = 148.5kW	Repeat of Run 2 on this sample. Result: Same result as in Run 2. Exposed surface looks smooth and shinny. Blue in color around the edges. Requires more power.
4	95-J23-6822-110-4	5% GD Silicate/XGL6 84-1	Grit Blasted Steel	4.6 - 5.6	725A 230V Power = 166.8kW	Test performed using above parameters. Power level increased in this Run. Result: Excellent. Coating melted into substrate. Surface looks smooth and shiny.
5	95-J23-6822-110-5	5% GD Silicate/XGL6 84-1	Nickel Flash	5.0 - 6.2	725A 230V Power = 166.8kW	Repeat of Run 4. Same type of sample as in Run 4 except the coating is on nickel flashed substrate. Result: Same as in Run 4.
6	95-J23-6822-111-2	94-J42-6996-16 10% GD Silicate/XGL6 84-2	Grit blasted steel	3.1 - 3.7	725A 230V Power = 166.8kW	Test performed using above test parameters. This sample has 10% of GD Silicate Binder when compared to samples in Runs 1, 3 & 4. Result: Excellent. Coating fused into substrate. Surface looks smooth and shiny.
7	95-J23-6822-111-3	10% GD Silicate/XGL6 84-2	Grit Blasted Steel	6.3 - 7.3	725A 230V Power = 166.8kW	Test performed using above test parameters. This sample has a bit thicker coating when compared with samples in Runs 2 and 6. Result: During the Run quite a bit of smoke was observed. The coating did melt into beads and got stuck to substrate. Upon cooling these beads of glass popped off.

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Run	Panel Identification	Coating/Binder Content	Substrate Type	Dry Film Thickness	Operating Current	Comments
8	95-J23-6822-111-4	10% DG Silicate/XGL6 84-2	Grit Blasted Steel	6.6 - 7.9	725A 230V Power = 166.8kW	Repeat of Run 7. Result: Same as in Run 7.
9	95-J23-6822-111-5	10% DG Silicate/XGL6 84-2	Nickel Flash	2.9 - 4.1	725A 230V Power = 166.8kW	Same set-up and same type of sample as in Run 6 except the coating is on nickel flash substrate. Result: Same as in Run 6.
10	95-J23-6822-112-1	94-J42-6996-15 15% GD Silicate/10% ilica/XGL684-	Grit Blasted Steel	4.8 - 5.6	725A 230V Power = 116.8kW	Test performed using above test parameters. This sample has a different % of binder content when compared with samples in Runs 1, 3 & 4. Result: A lot more smoke observed during the run. The coating did fuse into substrate but the surface does not appear as smooth and shinny as in Run 4.
11	95-J23-6822-112-3	94-J42-6996-15 15% GD Silicate/10% ilica/XGL684-	Grit Blasted Steel	4.7 - 5.6	725A 230V Power = 116.8kW	Repeat of Run 10. Result: Same as in Run 10.
12	95-J23-6822-112-3	94-J42-6996-15 15% GD Silicate/10% ilica/XGL684-	Grit Blasted Steel	7.9 - 9.5	725A 230V Power = 166.8kW	Test performed using the above test parameters. This sample has a thicker coating when compared with the sample in Run 10. Result: A lot more smoke observed. The coating did melt into substrate. Surface appears black, rough and I could see big beads of glass. Upon cooling these beads of glass popped off.

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Run	Panel Identification	Coating/Binder Content	Substrate Type	Dry Film Thickness	Operating Current	Comments
13	95-J23-6822-112-4	94-J42-6996-15 15% GD Silicate/10% ilica/XGL684-	Grit Blasted Steel	8.4 - 9.5	725A 230V Power = 166.8kW	Repeat of Run 12. Result: Same as in Run 12.
14	95-J23-6822-112-5	94-J42-6996-15 15% GD Silicate/10% ilica/XGL684-	Nickel Flash	4.9 - 6.8	725A 230V Power = 166.8kW	Same set-up and same type of sample as in Run 10 except the coating is on nickel flash substrate. Result: Same as in Run 10.
15	95-J23-6822-1132-1	94-J42-6996-16 20% GD Silicate/10% Silica/5% Bentone XGL684-4	Grit Blasted Steel	3.4 - 4.6	725A 230V Power = 116.8kW	Test performed using above test parameters. This sample has a different % of binder content when compared with samples in Runs 1, 3 & 4. Result: Coating did melt into substrate. Half of the sample's surface is rough with big beads. The other half is not to rough and beads look much smaller.
16	95-J23-6822-113-2	94-J42-6996-16 20% GD Silicate/10% Silica/5% Bentone XGL684-4	Grit Blasted Steel	3.4 - 4.6	725A 230V Power = 116.8kW	Repeat of Run 15. Result: Same as in Run 16.

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Run	Panel Identification	Coating/Binder Content	Substrate Type	Dry Film Thickness	Operating Current	Comments
17	95-J23-6822-113-3	94-J42-6996-16 20% GD Silicate/10% Silica/5% Bentone XGL684-4	Grit Blasted Steel	4.0 - 5.1	725A 230V Power = 166.8kW	Same set-up and same type of sample as in Run 15 except the coating thickness on this sample is a bit thicker. Result: Coating melted into substrate in big bead form. Upon cooling these glass beads popped off.
18	95-J23-6822-113-4	94-J42-6996-16 20% GD Silicate/10% Silica/5% Bentone XGL684-4	Grit Blasted Steel	4.3 - 4.7	725A 230V Power = 166.8kW	Repeat of Run 17. Result: Same as in Run 17.
19	95-J23-6822-113-5	94-J42-6996-16 20% GD Silicate/10% Silica/5% Bentone XGL684-4	Nickel Flash	4.0 - 4.8	725A 230V Power = 166.8kW	Set-up the same as in Run 15. On this sample the coating is on nickel flash substrate. Result: Same as in Run 15.

Conclusion: The best results acquired from the coating with binder contents of 5% or 10% GD Silicate/XGL684 and with dry film thickness of 5.0 mils. or less.

Note: It was observed that panels with binder content with 10% CAB 381.01 emit much more harmful smoke than panels with binder content with 10% GD Silicate. It was hard to stay in the room when 10% CAB 381.01 panel was treated under the Arc Lamp.

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ORTECH DREP Samples Phase II

Objective: To determine the effect of glass particle size in XG 684 coating.

Test Parameters:

- Rhodium plated reflector used
- Close couple ellipse reflector
- All samples scanned perpendicular to the arc
- All samples 2cm below the mouth of the reflector (i.e. 1cm below focus)
- Air sweep used
- All samples rested on #1032 studs
- All samples scanning velocity 1/4"/sec (i.e. 0.25"/sec)

Run	Panel Identification	Coating	Substrate Thickness	Dry Film Thickness (mils)	Operating Current	Comments
1	95-J23-6822-109-2 Binder Content 10%	XG 684 Fine Grid	1/2"	6.5-7.5	925A 255V	↓ Air sweep used, fully open. All tests performed using above test parameters. This run to establish right power level. Result: Exposed surface appeared black, rough & beaded. During the run, quite a bit of smoke was observed. Have to cut back on power.
2	95-J23-6822-109-1 Binder Content 10%	XG 684 Fine Grid	1/2"	6.5-7.5	900A	↓ Air sweep used, fully open. Repeat of Run 1 except power was slightly reduced. Result: Exposed surface appeared black, rough and beaded.

Run	Panel Identification	Coating	Substrate Thickness	Dry Film Thickness (mils)	Operating Current	Comments
3	95-J23-6822-108-1 Binder Content 10%	XG 684 Medium Grid	1/2"	6 - 8	900A	Air sweep used, fully open. Repeat of Run 1 on medium grid coating. Result: Exposed surface looks black, rough and beaded. Portion of the coating on the exposed surface of sample did not fuse. It was found that part of the reflector was covered under the smoke. The reflector was cleaned and seemed to be OK for the next run.
4	95-J23-6822-108-2 Binder Content 10%	XG 684 Medium Grid	3/8"	6 - 8	725A	Air sweep used. Test performed using above test parameters to establish right power for next run. Result: Exposed surface appears black, rough and beaded. A bit high in power. Reduce power for next run.
5	95-J23-6822-109-4 Binder Content 10%	XG 684 Fine Grid	3/8"	5.5 - 6.5	685A	Air sweep used. Test performed using above test parameters. Run 5 & 6 should be a comparison run between fine grid and medium grid coating. Result: Exposed surface appears rough and beaded.
6	95-J23-6822-108-3 Binder Content 10%	XG 684 Medium Grid	3/8"	6 - 8	685A	Air sweep used. Repeat of Run #5 on medium grid coating. Result: Same as in Run 5. Upon cooling some of this coating which formed into beads popped off. Run 5 & 6 samples exposed surface compared - not much of a difference.

Run	Panel Identification	Coating	Substrate Thickness	Dry Film Thickness (mils)	Operating Current	Comments
7	95-J23-6822-108-4 Binder Content 10%	XG 684 Fine grid	3/8"	6 - 8	685A	Air sweep used. Repeat of Run 6. Checking the repeatability of results. Result: Identical as in Run 6.
8	95-J23-6822-109-3 Binder Content 10%	XG 684 Fine Grid	1/2"	5.5 - 6.5	850A	Air sweep used. Test performed using above test parameters. Same as in Run 2 except the power was reduced. Result: Middle portion of exposed sample not much of the coating there - could see the substrate. This could be that the power was too high. Around the edges of the exposed surface there was a black, rough and beaded appearance.

Conclusion:

The glass particle size (fine grit and medium grit) did not have an effect when these panels were sintered.

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ORTECH DREP Samples Phase II

Objective: To determine if different substrates have any effect when sintering these panels.

Test Parameters:

- Rhodium plated reflector used
- Close couple ellipse reflector
- All samples scanned perpendicular to the arc
- All samples 2cm below the mouth of the reflector (i.e. 1cm below focus)
- All samples rested on #1032 studs.
- Samples translated at velocity of 1/4"/sec. (0.25"/sec.)
- Air sweep used on all the samples.

Run	Panel Identification	Substrate Type	Dry Film Thickness (mils)	Operating Current	Comments
1	95-J23-6822-114-1 Coating: XG684 Binder Content: 10% CAB 381.01	Grit blasted steel	3.9 - 4.8	550A	Tests were performed using above parameters. Result: Coating did not melt into substrate. Requires more power.
2	95-J23-6822-114-2 Coating: XG684 Binder Content: 10% CAB 381.01	Grit blasted steel	3.5 - 4.1	600A 215 V Power = 129kW	All tests performed using above test parameters. Result: Good. Coating well fused into substrate. Exposed surface appears shinny and quite smooth. Only around the edges it seems like the coating requires more power. Uniform flux density may cause this problem.

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Run	Panel Identification	Substrate Type	Dry Film Thickness (mils)	Operating Current	Comments
3	95-J23-6822-114-3 Coating: XG684 Binder Content: 10% CAB 381.01	Nickel flash	4.0 - 4.6	600A 215V Power = 129kW	Repeat of Run 2. The coating is on Nickel Flash substrate. Result: Good. Similar result as in Run 2. Around the edges only the coating looks a bit beaded.
4	95-J23-6822-114-4 Coating: XG684 Binder Content: 10% CAB 381.01	Nickel	4.0 - 4.5	600A 215V Power = 129kW	Repeat of Run 2. The coating is on Nickel plate. Result: Same as in Run 3..
5	95-J23-6822-114-5 Coating: XG684 Binder Content: 10% CAB 381.01	Grit blasted steel	7.2 - 7.8	600A 215V Power = 129kW	Test performed using above test parameters. This sample has thicker coating when compared to samples in Runs 1 & 2. Result: Not quite as smooth melting of coating into substrate. A bit rough and beaded.
6	95-J23-6822-114-6 Coating: XG684 Binder Content: 10% CAB 381.01	Grit blasted steel	7.2 - 7.8	600A 215V Power = 129kW	Repeat of Run 5 on a similar type of sample. Result: Identical to Run 5.
7	95-J23-6822-114-7 Coating: XG684 Binder Content: 10% CAB 381.01	Nickel Flash	3.4 - 6.3	600A 215V Power = 129kW	Repeat of Run 5. This sample coating is on Nickel Flash substrate. Result: Same as in Runs 5 & 6.
8	95-J23-6822-114-8 Coating: XG684 Binder Content: 10% CAB 381.01	Nickel Plate	6.5 - 8.6	600A 215V Power = 129kW	Repeat of Run 5. This sample coating is on Nickel Plate substrate. Result: Bad. Surface appeared rough and beaded. Upon cooling the glass beads popped off.

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Run	Panel Identification	Substrate Type	Dry Film Thickness (mils)	Operating Current	Comments
9	95-J23-6822-115-1 Coating: METCO 34F Binder Content 5% Elvanol 52-22	Grit Blasted Steel	3.0 -3.4	725A 230V Power = 166.75kW	Tests performed using above test parameters. This sample has tungsten carbide cermet coating on its steel substrate. Result: Excellent. Coating did melt into substrate. Exposed surface looks silvery and like 800 grit sandpaper.
10	95-J23-6822-115-2 Coating: METCO 34F Binder Content 5% Elvanol 52-22	Grit Blasted Steel	2.2 - 2.7	725A 230V Power = 166.75kW	Repeat of Run 9 on similar type of sample. Result: Not quite like in Run 9. Problem occured, reflector got some smut and reduced the reflectivity. The coating did not melt into substrate.
11	95-J23-6822-115-3 Coating: METCO 34F Binder Content 5% Elvanol 52-22	Nickel Flash	3.1 - 3.7	725A 230V Power = 166.75kW	Repeat of Run 9. This sample has tungsten carbide cermet coating on Nickel Flash substrate. Result: Same as in Run 9.
12	95-J23-6822-115-3 Coating: METCO 34F Binder Content 5% Elvanol 52-22	Nickel Plate	3.1 - 3.7	725A 230V Power = 166.75kW	Repeat of Run 9. This sample has tungsten carbide cermet coating on Nickel Plate substrate. Result: Same as in Runs 9.

Conclusion:

Different substrates such as grit blasted steel, nickel flashed and nickel plated did not have an effect when these panels were treated.

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